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DC-9 FLIGHT DEMONSTRATION PROGRAM WITH REFANNED JT8D ENGINES

FINAL REPORT

VOLUME II

DESIGN AND CONSTRUCTION

by

Douglas Aircraft Company
McDonnell Douglas Corporation
Long Beach, California 90846

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16. Abstract

During the period of June 1973 to July 1975, design, fabrication, and ground and flight testing of DC-9 Refan airframe/nacelle hardware with prototype JT8D-109 engines, was conducted.

The nacelle configuration selected had 1595.6 mm (62.82 in.) length inlet and an 1811.8 mm (71.33 in.) exhaust duct. The inlet had 1234.4 mm (48.6 in.) of acoustic treatment and the tailpipe had 1305.5 mm (51.4 in.) of equivalent length acoustic treatment. The pylon was reduced in width from 425.5 mm (16.75 in.) to 204.5 mm (8.05 in.). Fuselage frames and titanium skin panels in the area of the pylon were reinforced or replaced to support the higher loads and engine thrust. Experimental type tooling, fabrication and assembly was used on all hardware.

The design is considered certifiable and representative of the hardware that would be built as retrofit kits.

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SUMMARY

The purpose of the DC-9 Refan Program was to establish the technical and economic feasibility of reducing the noise of existing JT8D powered DC-9 aircraft. The Refan Program was divided into two phases.

Phase I provided engine and nacelle/aircraft integration definition documents for installation of the JT8D-109 Refan engine on the DC-9 series aircraft, prepared preliminary design of nacelle and airplane modifications, conducted model tests for design information, and prepared analyses for economic and retrofit considerations. Phase II included detail design, hardware fabrication, and flight testing to substantiate the design and obtain flyover noise data.

The JT8D-109, the Refan derivative of the basic JT8D-9 engine with the minimum treatment acoustic nacelle was selected from Phase I for the design, analyses, construction and flight testing during Phase II. The work described in this report documents the design and construction effort carried out under this phase of Contract NAS 3-17841.

The heavier larger engine and nacelle with the higher thrust engine required a decrease in pylon span or width. Wind tunnel tests and accessibility to systems passing through the pylon resulted in a final width of 204.5 mm (8.05 in.) versus a production width of 425.5 mm (16.75 in.). The pylon was designed to a deflection criteria in order to maintain the fatigue structural integrity of the pressure bulkhead.

The fuselage frames in the area of the pylon and the keel beams in the wheel well area were increased in strength through the use of doublers or add-on structural members in order to take the increased loads.

The titanium structural panel (fuselage skin in pylon area) was removed and replaced with a heavier gauge for the increased loads and to act as a fire resistant barrier.

The nose cowl was constructed with an inner barrel fabricated from bonded aluminum honeycomb sandwich and an outer skin and leading edge lip fabricated from formed aluminum sheet. The effective treatment length was 1.3 m (48.6 in.). The leading edge was anti-iced by ducting hot air into the D-duct. An aft bulkhead closes the inner and outer skins and forms a land for the forward edge of the nacelle upper and lower access doors.

The access doors and aprons are similar in concept to the production doors, however, five latches and hinges were required instead of the four used on production. It was constructed of circumferential frames with closing beams. Small access holes for CSD service, ram air vent, fuel drain, etc. were provided.

The exhaust duct was made in two segments. The aft segment was canted to maintain the same thrust line through the aircraft center of gravity as the production aircraft. To achieve the desired performance with an acoustic treatment ratio of 1.65 the exhaust duct was increased in overall length from the production 1.37 m (54 in.) to 1.85 m (71.33 in.).

The reverser was attached to the aft segment of the exhaust duct and was a scaled-up version of the production target-type reverser. The reverser was oriented on each of the two pods such that the lower reverser gas efflux was directed 15° from the vertical away from the airplane centerline in order to alleviate ingestion problems.

Subsystems were redeveloped; however, the concepts were the same as the production DC-9.

The nose cowl, thrust reverser and exhaust duct, as well as most subsystems are common to either the left hand or right hand engines.

INTRODUCTION

The continuing growth of the air transportation industry with resulting increased numbers of operations from established or emerging airports coupled with increased population density near airports have resulted in increased public exposure to aircraft noise. The government and industrial organizations have therefore aggressively supported programs directed at producing airplane and engine designs offering meaningful reductions in airport community noise.

During the late 1960's research related to the noise within the engine itself and research related to absorptive materials were sufficiently refined to have been applied to the development of the quieter high-by-pass-ratio turbofan power plants for the new generation of wide-body commercial transports.

However a large portion of the existing and expanding fleet of standard bodied transports are powered by the JT3D or JT8D low-by-pass-ratio engines. Since early retirement of these aircraft or refitting with totally new high-by-pass-ratio engine are not competitive in terms of timeliness or economics, two approaches to solve the noise problem of these low-by-pass-ratio engines appear to be feasible. One approach would be to apply the technology of sound absorbing materials (SAM) to nacelle treatment with possibly a jet noise suppressor. A number of government and industry studies have considered this approach (SAM) and standard body transports being delivered in the mid-1970's include this technology.

A second approach would be to incorporate the technology of the high-by-pass-ratio engines into the JT3D and JT8D family. This would require replacement of the present low-by-pass-ratio engine two stage fans with a larger diameter single-stage while maintaining the hardware and general operating characteristics of the core engine. This would result in a substantial reduction in jet exhaust noise, of particular interest for the JT8D engine, with the possibility of improved engine fuel consumption with a substantial improvement in thrust.

In August 1972 the NASA Lewis Research Center authorized the Douglas Aircraft Company, The Boeing Company, and Pratt and Whitney to develop and demonstrate the economic and technical feasibility of reducing noise by developing engine and airframe/nacelle modifications. The program covered The JT3D engine and the DC-8 and B-707 it powers and the JT8D engine and the DC-9, B-727 and B-737 it powers. At the end of approximately four and one-half months all effort on the JT3D was terminated. All subsequent studies were performed on a derivative of the Pratt and Whitney JT8D-9 engine designated the JT8D-109. The Douglas Aircraft Company Phase I effort is reported in reference 1.

Based on the results of the Phase I effort the Douglas Aircraft Company was authorized on 30 June 1973 to proceed with a Phase II program that would include the nacelle/aircraft design and construction, kit costs, ground engine/nacelle compatibility tests, and flight tests which included flight worthiness, engine/aircraft performance and flyover noise tests.

This volume (Volume II) contains the design effort that established the configuration for the nacelle, pylon, thrust reverser, subsystems, and fuselage including the construction of the refanned hardware.

"DC-9 Flight Demonstration with Refanned JT8D Engines - Summary" is shown in reference 2. Reference 3, "Performance and Analysis", contains the engine/aircraft performance, flight test results, supplemental test results, structural analysis, and the economic and retrofit analysis. Reference 4, "Flyover Noise", contains the FAR Part 36 noise results, noise exposure contours, and supplemental noise analysis for Phase II of the Douglas effort on the NASA Refan program.

This report contains both U.S. Customary and S.I. Units; however, all calculations and measurements are made using the U.S. Customary Units.

DESIGN AND CONSTRUCTION PLAN

The refanned airplane, with its engines and associated subsystems, represents a design configured to obtain a substantial benefit from improved performance and noise characteristics. Considerable effort during the preliminary design of Phase I was directed toward the nacelle treatment that would ensure the final configuration represented the most effective application for the selected design. The prime goal was to retrofit the existing DC-9 fleet with a design that would provide for:

- Optimized acoustic treatment
- Minimum or no change to subsystems
- Same or improved subsystem reliability, accessibility, maintainability, and interchangeability
- Maximum commonality between left and right hand nacelles
- Minor aerodynamic and structural modifications to pylons and fuselage
- Little or no detrimental effect of the new nacelles on deep stall characteristics
- Minimize the effect of larger nacelles on cruise drag characteristics (i.e., no interference drag)
- Operational characteristics commensurate with production installation
- No degradation of airplane performance characteristics

As the various Refan designs and analyses progressed, design reviews were conducted. When approval was obtained a memorandum was issued to freeze design. NASA participated in monthly program design reviews. Copies of all Refan drawings were forwarded to NASA for reference.

A change control system was initiated at the start of drawing release wherein all drawing changes were approved jointly by the Program Office and the manufacturing management. In cases of disagreement a review and justification of a change was accomplished in the shop area.

The selection of tools and shop aids for Refan hardware was based on 'one of a kind' parts and assemblies, plus limited retrofit capability. Permanent forming dies and assembly jig fixtures associated with long production run parts were not used. Modifications were made to existing production fixtures by use of removable adaptors, wherever possible. Hand-fitting and trimming were performed during assembly buildup. The engine mount yoke fittings were hand machined using tooling templates and machining sequence instructions. Plaster forming and assembly tools of the type used in experimental work at Douglas successfully accomplished the forming and assembly.

During the early design stages, tooling and manufacturing representatives kept on-the-board contact with the designers and were able to evaluate the design for tool requirements, ease of manufacturing and special material forming. This coordination resulted in tool design and tool fabrication adequate for forming inconel, titanium, acoustical honeycomb panels, in addition to normal aluminum sheet metal and machined aircraft parts. Manufacturing was able to inject cost saving ideas directly into the basic designs prior to release. Outside manufacturers were also brought in during the formative design period to work with engineering, tooling, and manufacturing to reach an optimum design.

Production was controlled by a manufacturing plan and schedule which sequenced fabrication, assembly and installation of Refan hardware on DC-9 Ship No. 741. Existing manufacturing procedures were adequate for Refan development, fabrication and assembly activity.

A special area adjacent to a Refan designated parts control booth provided space and ready access to parts for Refan subassembly hardware and Class III mockup development activities. Maximum use was made of the Pratt and Whitney mockup engine to develop ducting, tubing, engine controls and wiring between hard points. Check fitting and functional checkout of the engine inlet cowl, exhaust duct and thrust reverser system were achieved on the Class III mockup fixture. All remaining development work was accomplished shipside.

The decision to modify DC-9 Ship No. 741 to a Refan configuration on the assembly line required special handling to assure that Refan hardware remaining on the airplane when it was returned to a salable configuration would be certifiable.

Refan modifications to Ship No. 741 fuselage structure were FAA inspected and approved. All Refan hardware was designed, fabricated, installed and found to be airworthy and qualified for an experimental flight (certification) ticket under Federal Aviation regulations. Douglas Quality and Reliability Assurance personnel were used throughout the program for inspection of all parts, assemblies and installation.

AIRFRAME STRUCTURAL REWORK

The installation of the JT8D-109 engine requires structural modification or redesign of the pylon, the fuselage, and the engine mount system. These modifications or new parts were required for the assembly of the Refan aircraft on the production line. The pylon structure will be removed during refurbishment of the aircraft to its production specification; however, the fuselage structural modifications will remain with the aircraft and are FAA inspected.

Pylon Construction

The Refan pylon shown in figures 1 and 2 was configured after evaluating a number of interrelated goals. Tests were conducted in Phase I, references 5 and 6, to determine the minimum pylon width considering both high speed cruise drag and low speed stall recovery. Three configurations were selected as shown in figure 3. The results of the test concluded that the Refan nacelle could be installed on a pylon from 132 mm (5.2 in.) to 279.4 mm (11.0 in.) in width without detriment to aircraft performance or stability characteristics.

Utilizing these minimum widths a study was made to determine access requirements for the subsystem connections. The connectors must be accessible for individual installation and removal, with standard tools, through access doors in the lower surface.

Because of the relatively narrow pylon, it was found to be difficult and time consuming to finalize these requirements by layout only, therefore, a full scale mockup of the pylon was constructed from styrofoam board. This mockup was bounded by the front mount spar, a point 304.8 mm (12 in.) aft of the rear mount spar, the closing rib and the fuselage skin. All of the subsystems were manufactured from wire, cardboard, and rubber hose, and were mounted in various trial positions in the pylon. At the same time various combinations of door sizes and positions were tried in the lower skin until a suitable configuration evolved. The optimum configuration included four doors in the pylon box and one door in the trailing edge fairing just aft of the rear spar.

Hydraulics, P_{T2} and P_{T7} were to be accessible through the forward door; the 8th and 13th stage bleeds, and the fire extinguisher pipe, through the two forward doors; and the electrical connections through the aft two doors. In the trailing edge fairing, access was required to torque the nut on the aft engine mount and also for installation and removal of the two thrust reverser hydraulic hoses. Final sizing of the doors was determined by aircraft maintenance and installation experience which indicated that four openings of 195.5 mm (7.7 in.) x 111.7 mm (4.4 in.) in the main pylon box, and one opening of 238.7 mm (9.4 in.) x 99 mm (3.9 in.) in the trailing edge fairing provided the minimum size apertures for servicing.

In order to provide adequate clearances and pylon structure on either side of the doors, a pylon of 204.5 mm (8.05 in.) was configured (figure 4) that met all known requirements.

<u>Box structure</u>. - With the configuration established, the major design consideration was to ensure that no fatigue problem would result due to any large relative deflections between the pylon and the fuselage skin. A design goal of 2.54 mm (0.1 in.) relative deflection between the pylon and fuselage was selected as sufficiently small such that lateral loads into the fuselage pressure bulkhead would not result in any fatigue problem. The critical condition was maximum takeoff thrust with fuselage pressure.

The pylon structural arrangement was similar to the production DC-9. The forward and rear engine mount spars are bolted rigidly to fuselage frames

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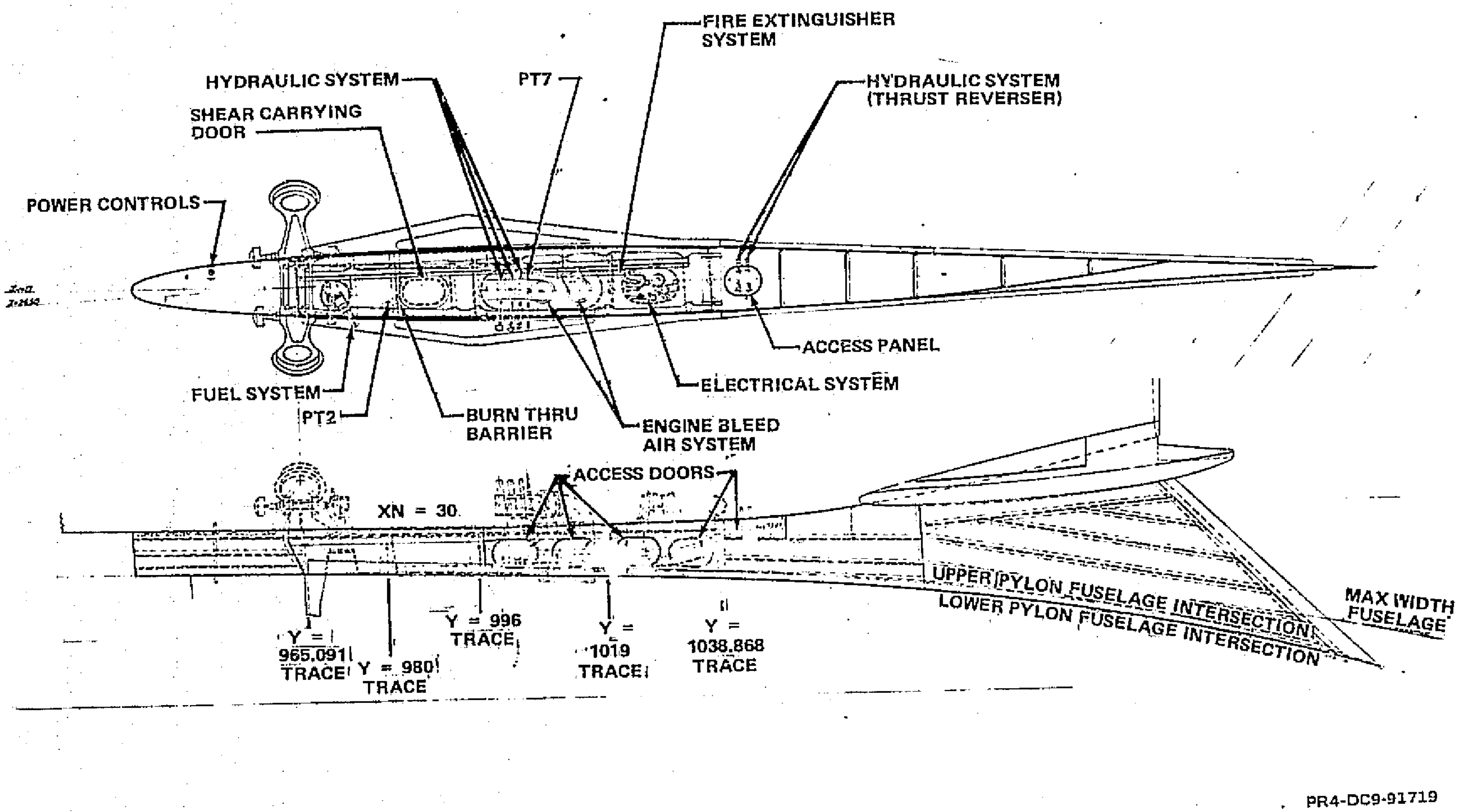

FIGURE 1. PYLON GENERAL ASSEMBLY

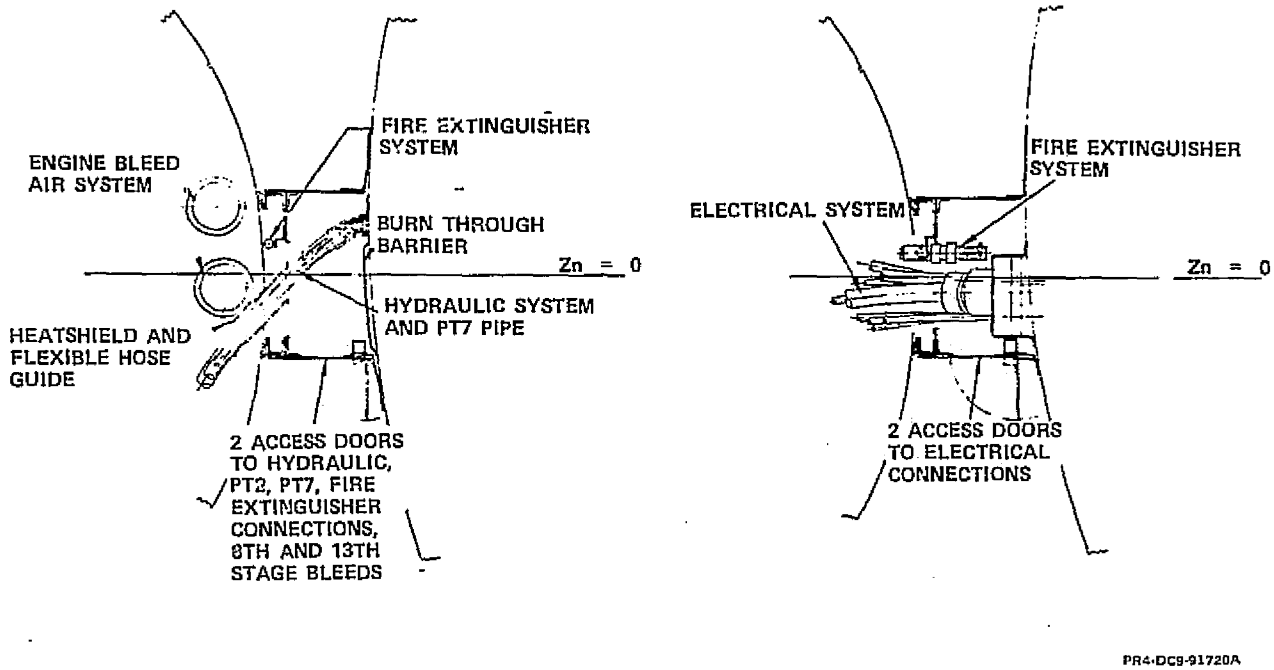

FIGURE 2. SERVICES PASSING THROUGH PYLON

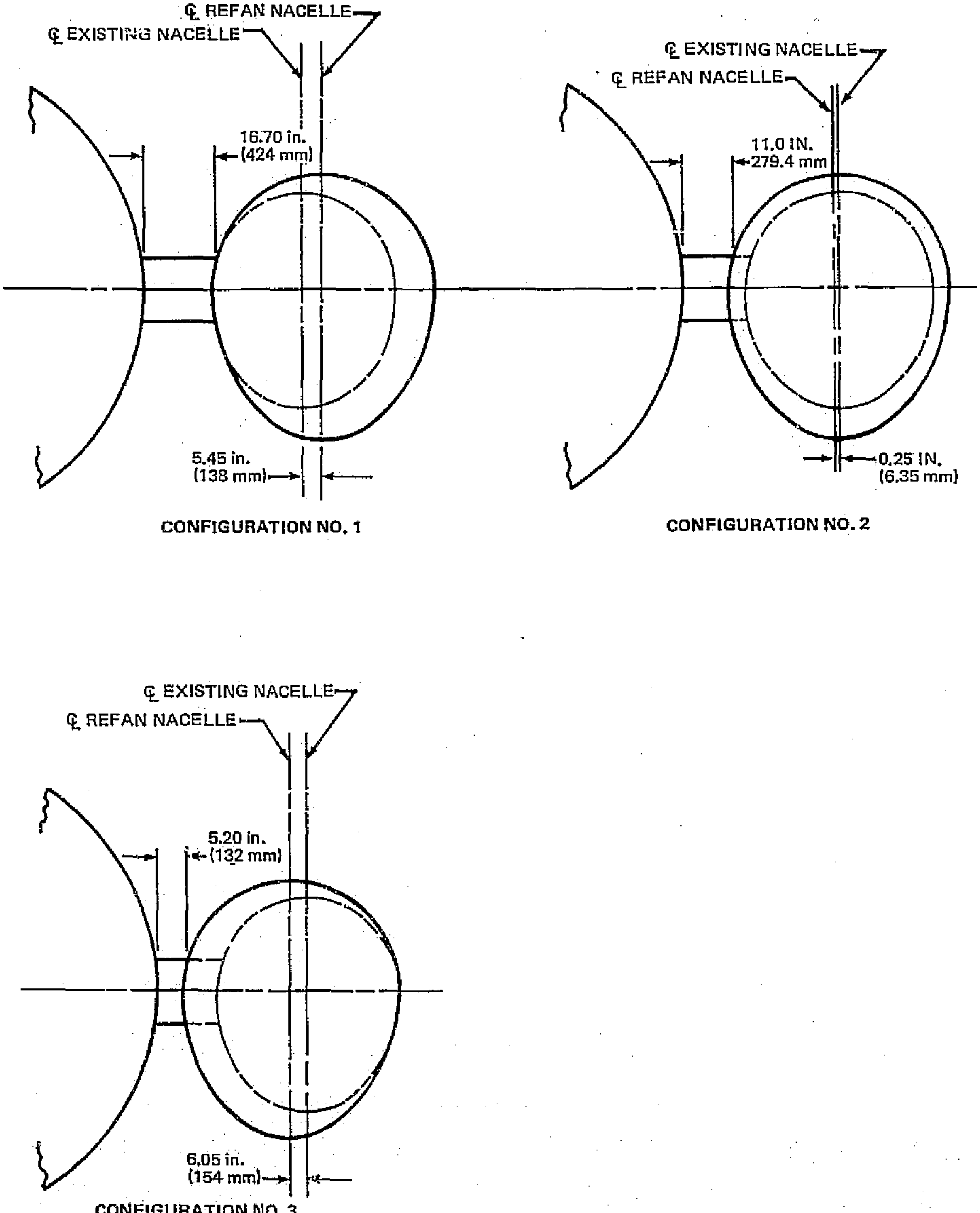

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FIGURE 3. PYLON STUDY CONFIGURATIONS

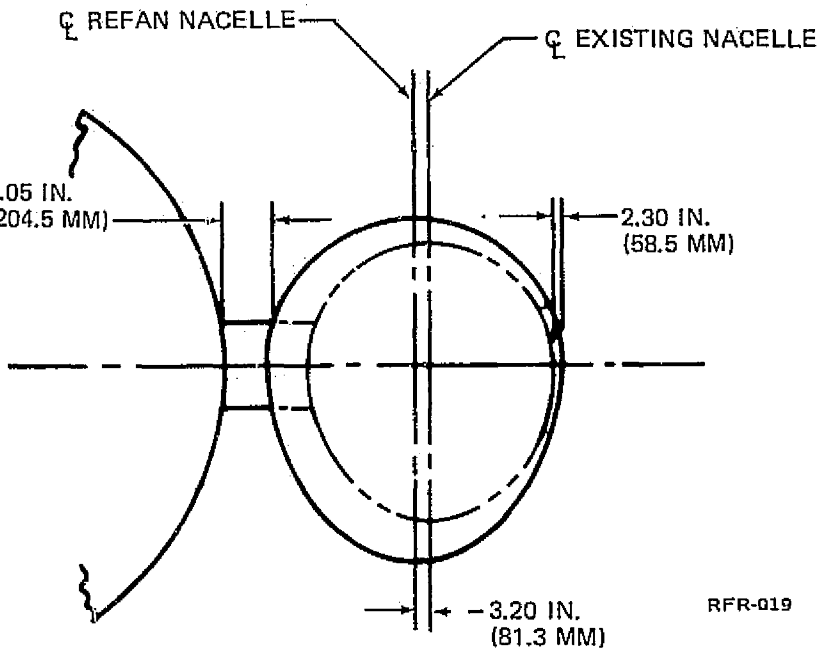

FIGURE 4. SELECTED PYLON CONFIGURATION

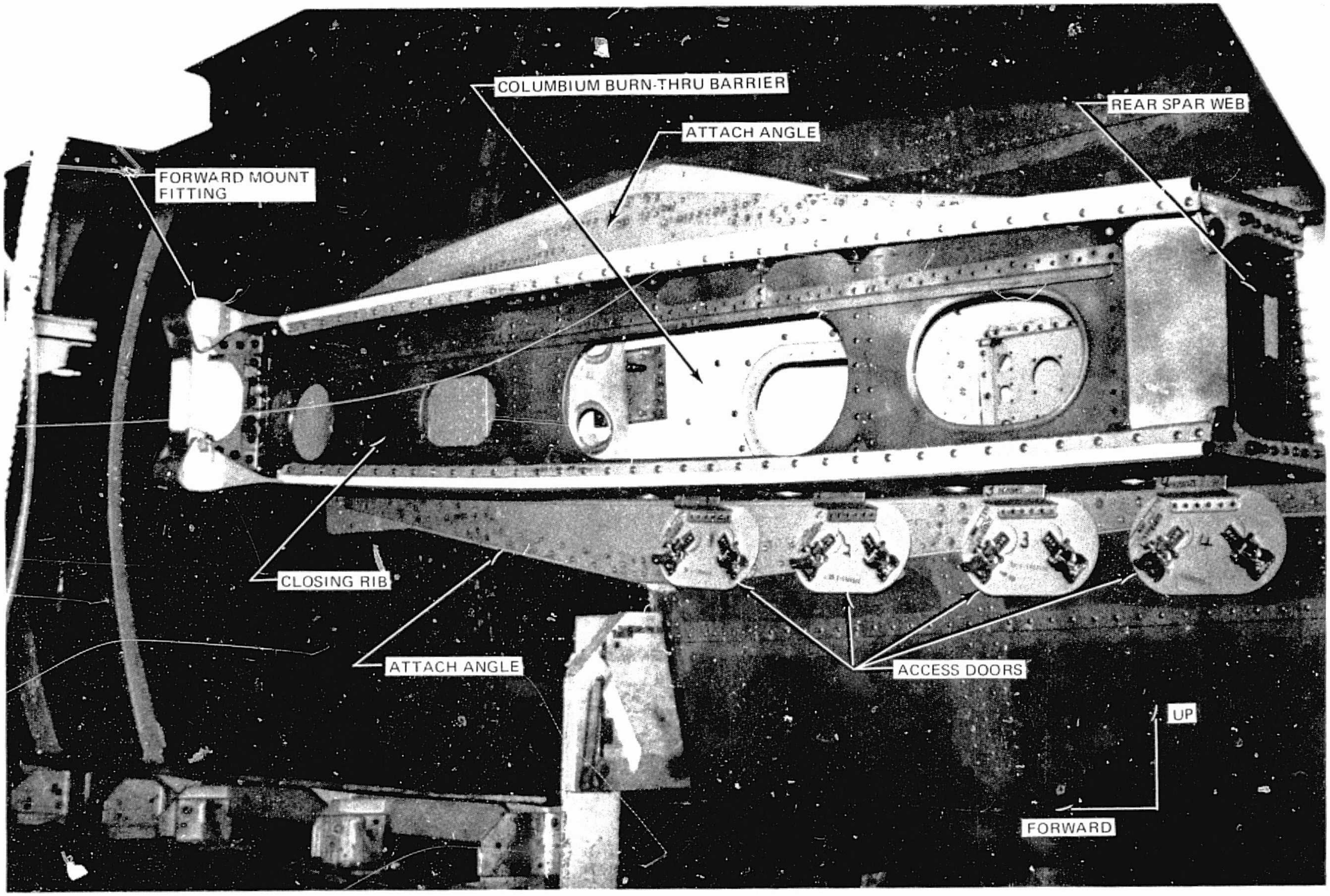

FIGURE 5. DC-9 REFAN PYLON BOX STRUCTURE

Y = 965.091 and Y = 1038.868. On the upper and lower skins, machined fittings are bolted to fuselage frames Y = 980 and Y = 1019. At Y = 996 the pylon center diaphragm is tied by means of a flexible fitting to the aft fuselage pressure bulkhead. Flexing fuselage attach angles are used over the entire length of the pylon main structural box on both the upper and lower surfaces. The upper surface of the pylon is fully skinned with no access holes, the lower skin has four doors cut in its aft end. The outer edge of the skins, rubber seals are attached (figure 5) which are compressed by the nacelle apron.

In order to obtain the correct M/I, it was necessary to design the pylon with fairly large cap members at the inboard and outboard edges. Because of the narrow width, this was achieved by adding external straps to the upper and lower skins at the closing rib and the fuselage attach angles.

The material selected for the box structure is indicated in figure 6.

The pylon box was built up in the Refan assembly area (figures 7 and 8) and attached to the fuselage on the production line, using existing placement tools modified for the reduced width (figures 9 and 10).

Leading edge. - The leading edge has the same aerodynamic shape as the production DC-9 and was constructed of one skin and two ribs. The leading edge was cantilevered off the upper and lower front spar fittings instead of being attached to the fuselage skin by means of angles. The smaller width pylon did not permit the use of the production DC-9 system of an inlet for inflight cooling and ventilation air in the lower pylon surface. Therefore, inlet holes were placed in the leading edge and pylon front spar.

To reduce costs, as many of the existing production leading edge parts were used as possible. The skin was cut in width, but not chem milled. Production caps were used for the two ribs. Also the rubber seals and retainers adjacent to both the nacelle apron and fuselage skins were production parts. The rib nearest the fuselage was manufactured from steel in order that it could become a secondary firewall with the outboard rib manufactured from aluminum. Access panels were put in both ribs to facilitate assembly to the front spar fittings and also installation of the throttle control cable.

The leading edge was built in the Refan assembly area and attached to the main pylon box in the Flight Development Center. The material used for the leading edge structure is indicated in figure 11.

Trailing edge. - The trailing edge of the pylon had the same aerodynamic shape as the production DC-9, and it is similar in construction. The main difference was the reduction in width by approximately 222.25 mm (8.75 in.). The trailing edge is constructed of 4 skins, a bulkhead, two steel and titanium ribs which are used as secondary firewalls, a number of aluminum ribs running in a fore and aft direction, and a trailing edge tip fairing. Attachment to the fuselage is made by means of angles. The outer edges have rubber seals attached that are compressed by the nacelle apron and thrust reverser.

The trailing edge utilized as many existing production parts as possible, with some parts being modified.

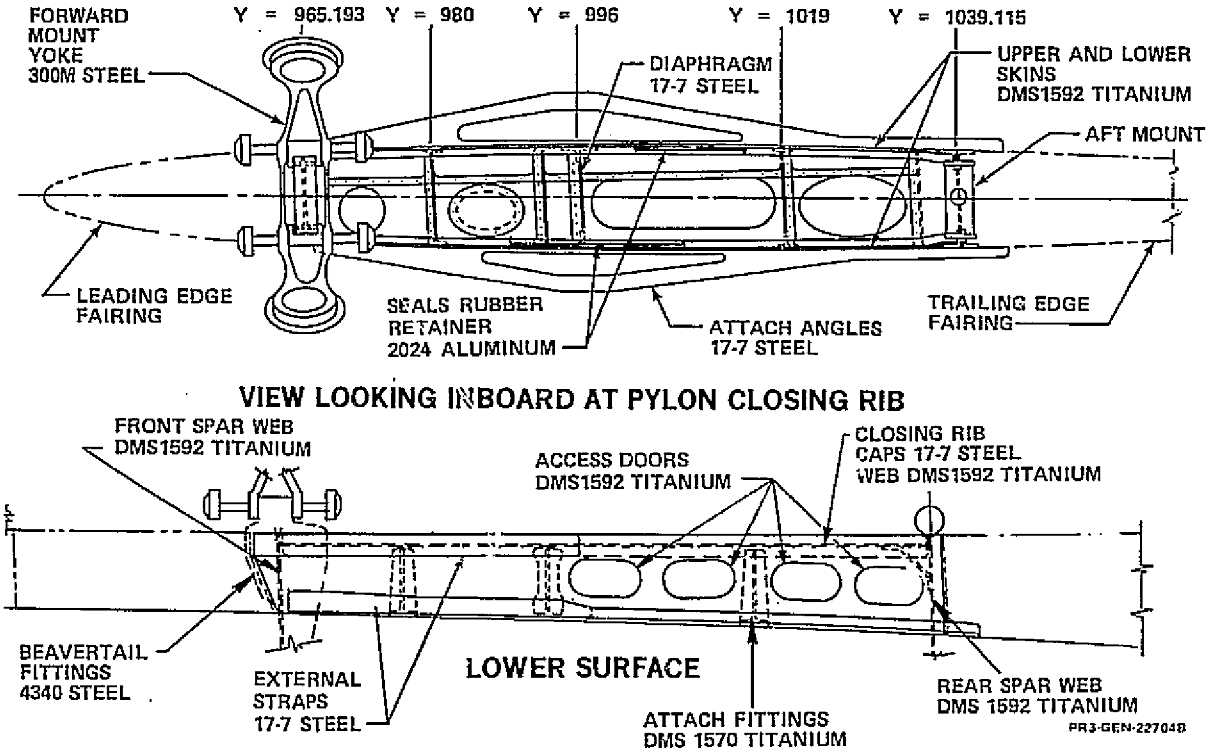

FIGURE 6. REFAN PYLON BOX STRUCTURE

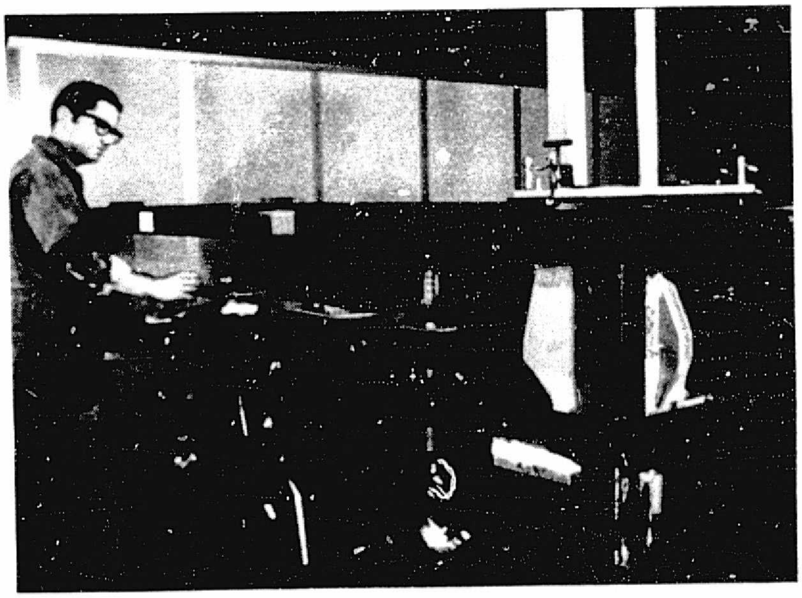

FIGURE 7. FRONT SPAR CAPS IN TOOL

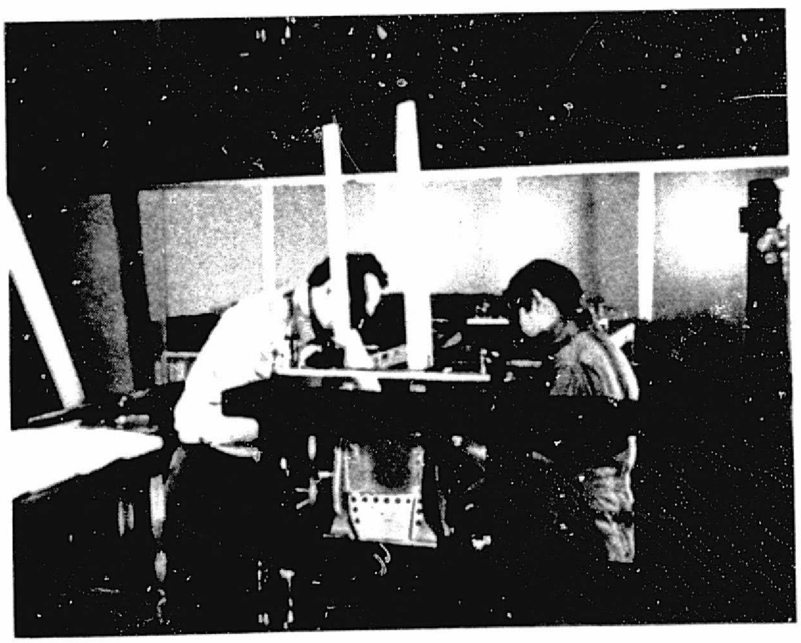

FIGURE 8. PYLON BOX IN TOOL

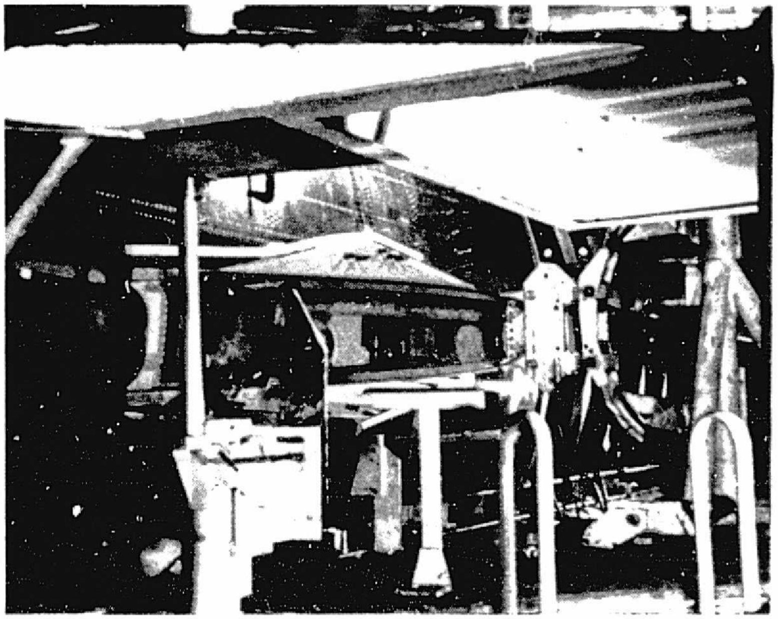

FIGURE 9. PYLON IN FUSELAGE ATTACH TOOL

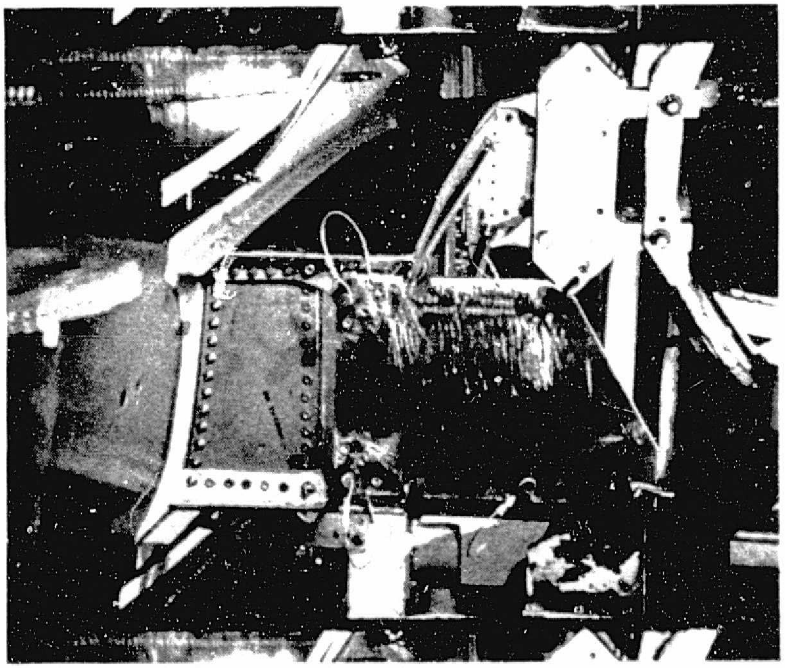

FIGURE 10. REAR PYLON SPAR IN FUSELAGE ATTACH TOOL

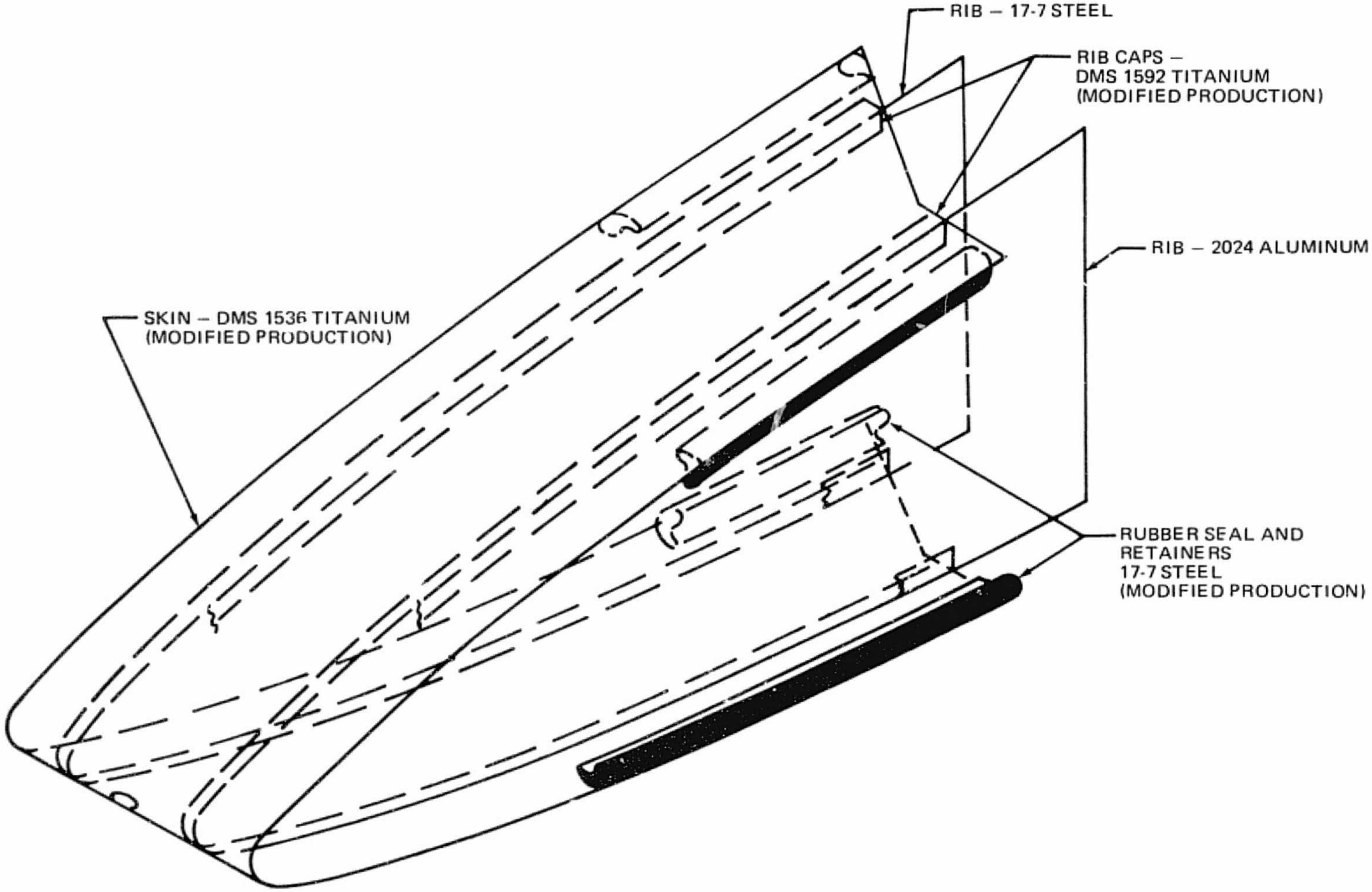

FIGURE 11. PYLON LEADING EDGE

The trailing edge was constructed in the Refan assembly area and was attached to the fuselage skin and main pylon box at the rear spar, in the Flight Development Center.

The material used for the trailing edge structure is shown in figure 12.

Fire protection. - Due to the decrease in pylon width the production secondary firewall positioned approximately 101.6 mm (4 in.) from the fuselage (not required by FAA regulations), was deleted and the thicker titanium fuselage skin panel serves in its place. To give maximum fire protection at points where the subsystems pass from the pylon into the fuselage, fireproof boxes are mounted on the fuselage skin. One at the fuel pipe, one at the 8th and 13th stage bleed ducts, (this box is covered by the columbium burn thru barrier), and two at the electrical connections, one on the inside and one on the outside of the fuselage skin. The production glass fibre phenolic resin burn thru barrier, located in the area of the engine burner cans and mounted on the secondary firewall, was replaced by a plasma sprayed columbium burn thru barrier attached 10.1 mm (.40 in.) outboard of the fuselage skin. See figure 13. The new barrier will stand 1093°C (2000°F) for 15 minutes (fluid fire) or 1648°C (3000°F) at 24.60 kg/sq cm (350 psi) for two minutes (burn thru). This allows time for engine shut down. The burn thru barrier, figure 14, was formed in-house and then sent to an outside vendor for plasma spraying. It was attached to the fuselage skin before installation of the pylons. The fireproof boxes were assembled to the skin at various positions on the assembly line.

Cooling and ventilation. - The pylon cooling and ventilation system has not changed in concept, and only in minor detail from production.

Because of the narrower width of pylon, it was impossible to put an inlet for inflight cooling air in the lower surface, as on production. Therefore two circular holes were made, one in the pylon leading edge, and one in the pylon front spar. Air circulates through the leading edge fairing, along the pylon box, and vents into the nacelle through the various service holes in the pylon closing rib, as shown in figure 15.

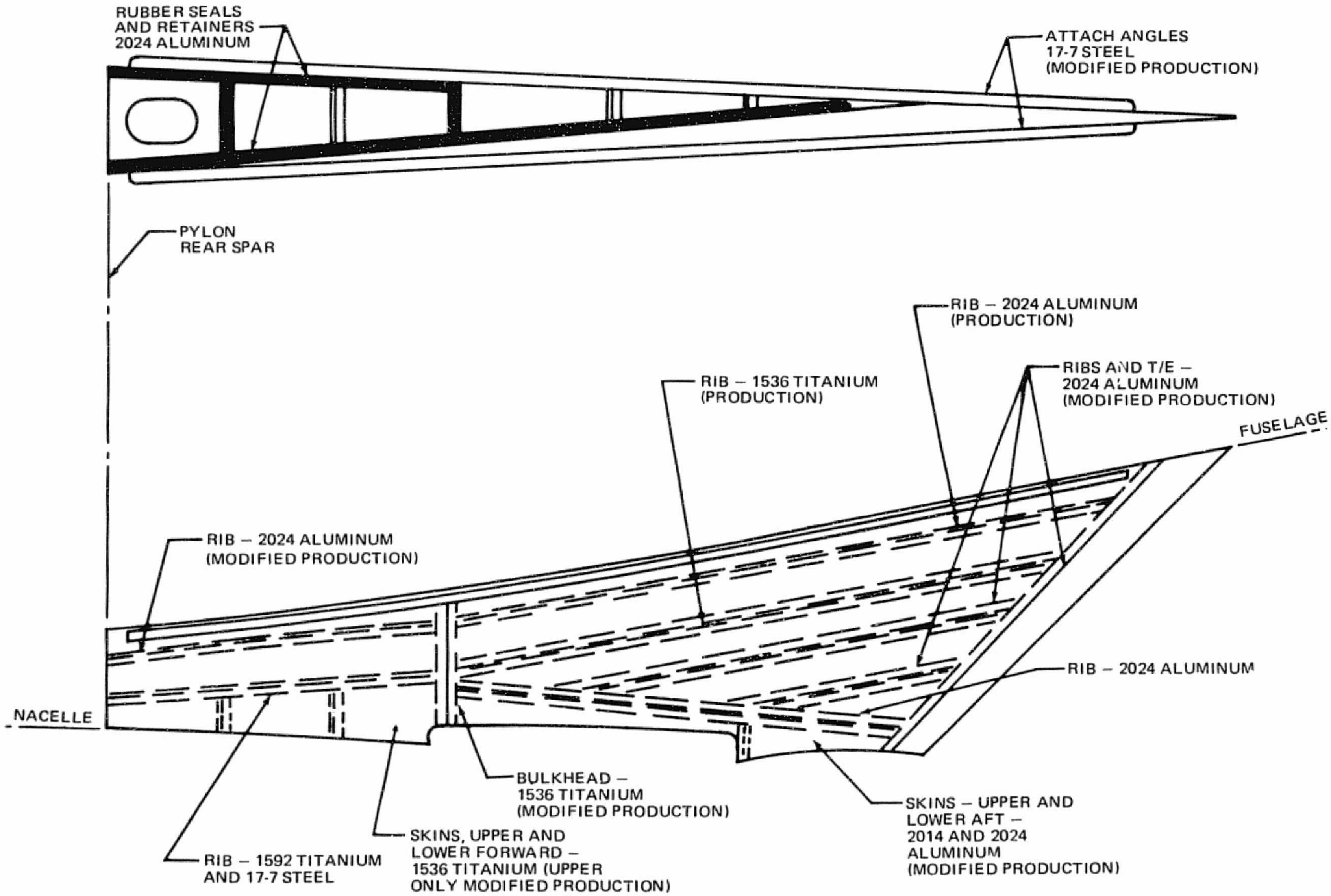

FIGURE 12. PYLON TRAILING EDGE

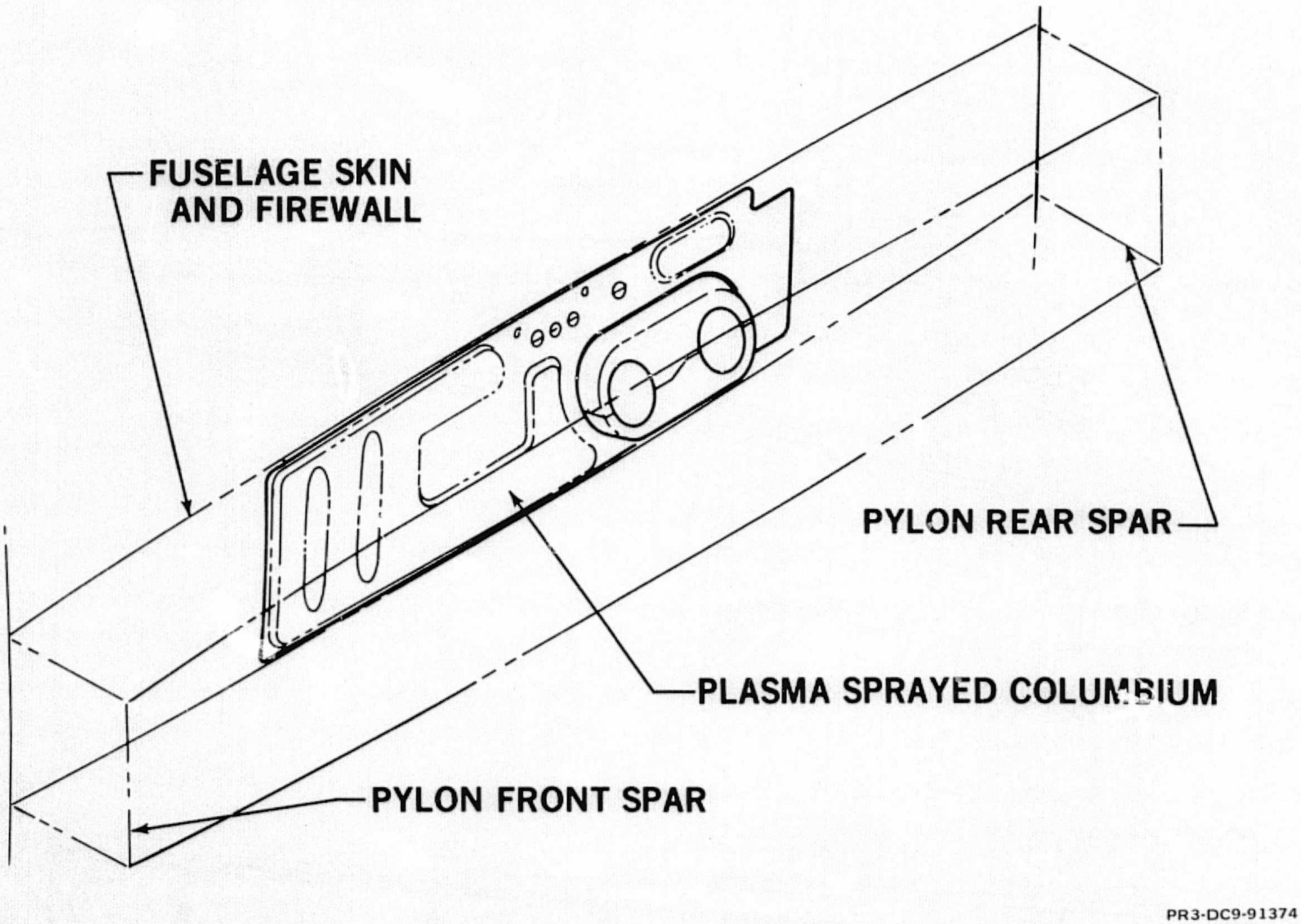

FIGURE 13. PYLON BURN-THROUGH BARRIER

FIGURE 14. BURNTHROUGH BARRIER

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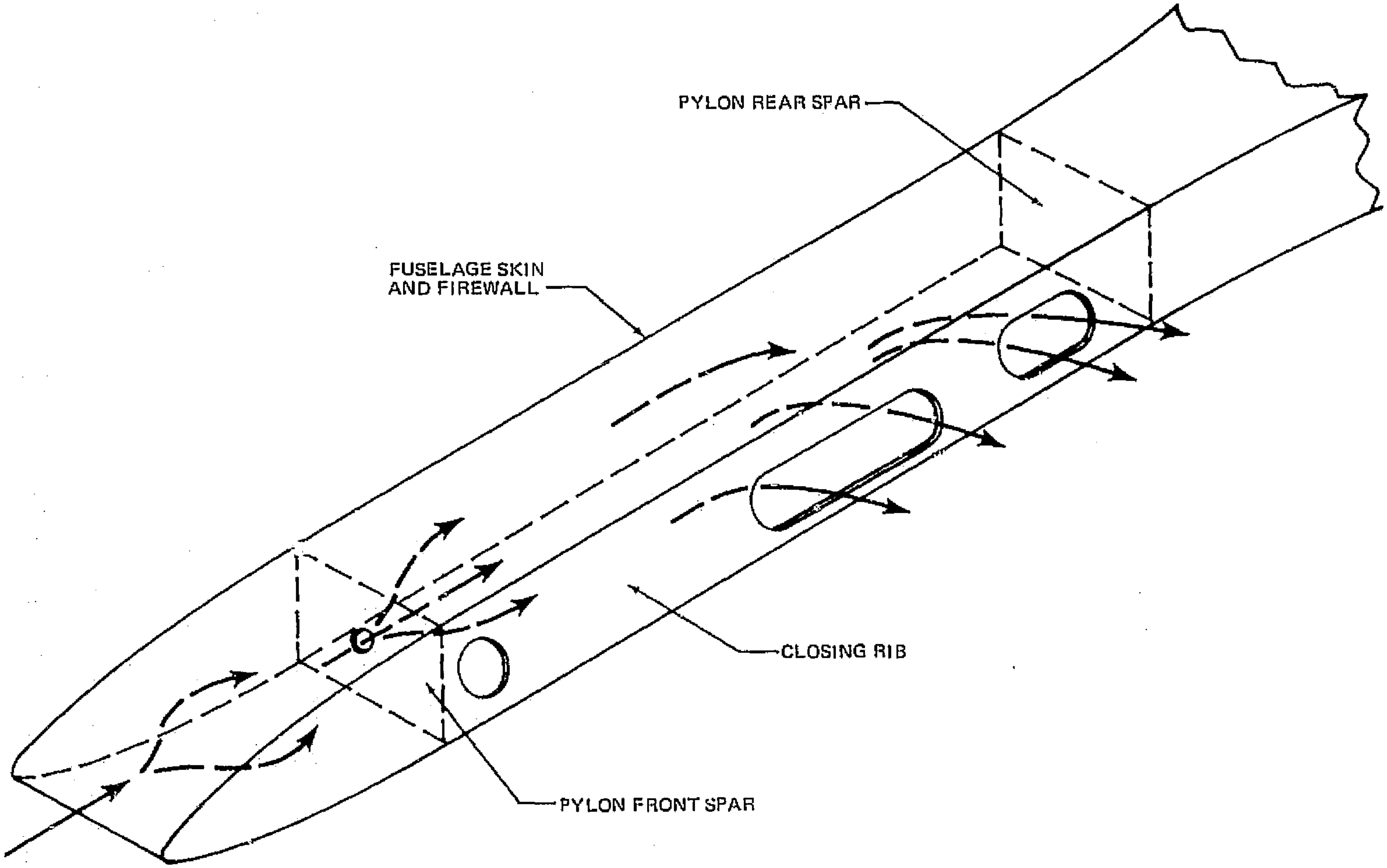

FIGURE 15. PYLON COOLING AND VENTILATION

Fuselage Rework

Because of the higher static and dynamic loads imposed on the fuselage by the installation of the JT8D-109 engine, nacelle, and pylon, analysis showed that it was necessary to:

- Replace the fuselage skin panels adjacent to the pylon with heavier gauge material.
- Reinforce the front spar mount frame at Y = 965.091.
- Reinforce the two intermediate frames at Y = 980 and Y = 1019.
- Reinforce the rear spar mount frame at Y = 1038.868.

Aft fuselage. - The production aft fuselage skins are generally manufactured from aluminum, except in the area adjacent to the pylons, where there are three titanium panels on each side of the aircraft. Because of the higher shear loads, it was found necessary to remove the skin panel bounded by frames Y = 937, Y = 996, and longerons 14 and the fuselage floor, and also the panel bounded by Y = 996, Y = 1087 and longerons 14 and 18. These panels of .812 mm (.032 in.) thickness with .812 mm (.032 in.) doublers were replaced by panels 3.17 mm (.125 in.) thick chem-milled down to 2.03 mm (.080 in.) and 1.27 mm (.050 in.). No changes were made to longerons and clips in this area. See figure 16.

The large aft production fuselage skin panels are subcontracted and shipped to Long Beach for assembly on the production line. For the Refan aircraft, two of these panels, one for the left and one for the right side of the aircraft, were taken to the Refan assembly area and reworked. First the titanium panels adjacent to the pylon were removed, by drilling out the existing fasteners, then the thicker titanium panels were attached in their place, using .406 mm (.016 in.) and .812 mm (.032 in.) oversize fasteners of the same type. See figure 17 and 18. The replacement 3.17 mm (.125 in.) thick panels were hot stretch formed for McDonnell Douglas by an outside vendor, and then chem-milled in plant. The forward panel is shown in figure 19.

The front spar mount frame at Y = 965.091 was reinforced by removing the existing aluminum web and doubler, from just above longeron 13 down to the fuselage floor, figure 20, and replacing it with thicker components manufactured from titanium. Various stiffener reinforcings, and fittings were then added.

The two frames at Y = 980 and Y = 1019 were reinforced by means of cap stiffening strips and web doublers, in order that they could take the loads imposed on them by the upper and lower pylon attach fittings, figure 21.

The rear spar mount frame at Y = 1038.868 was reinforced by removing the existing aluminum web, from just above longeron 8 to just below longeron 24,

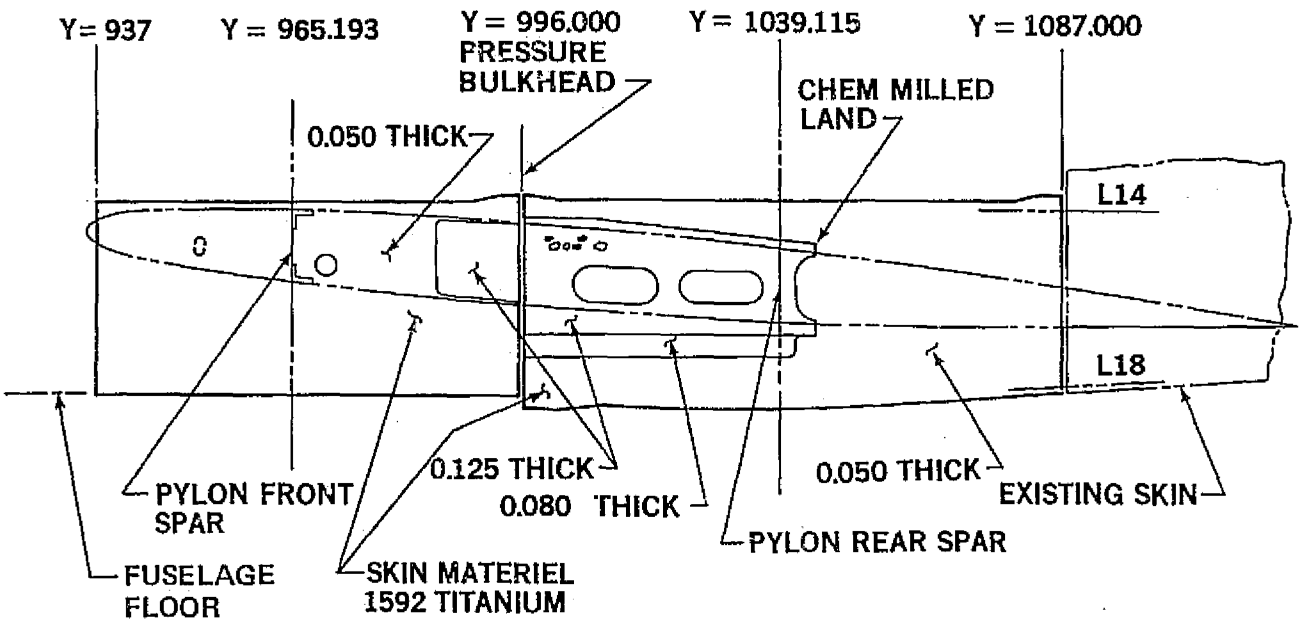

FIGURE 16. FUSELAGE SKIN (TITANIUM)

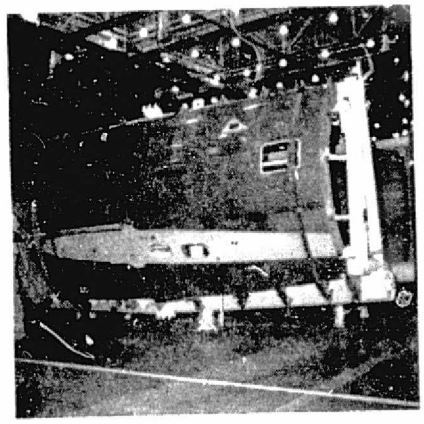

FIGURE 17. AFT FUSEL/ E SKIN PANEL

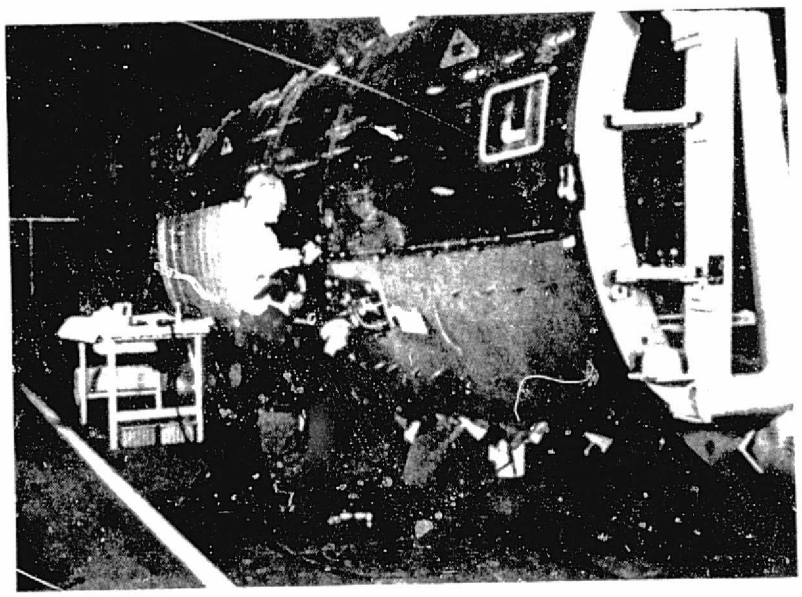

FIGURE 18. SIDE AFT SKIN PANEL – REWORK

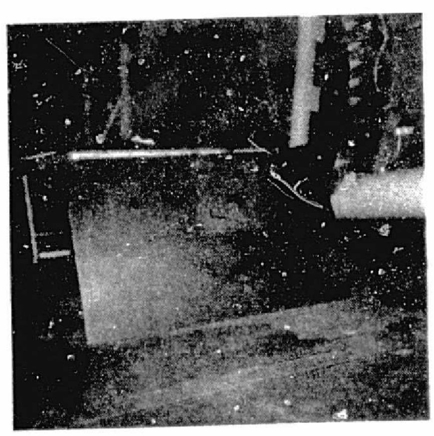

FIGURE 19. AFT FUSELAGE – FORWARD TITANIUM SKIN PANEL

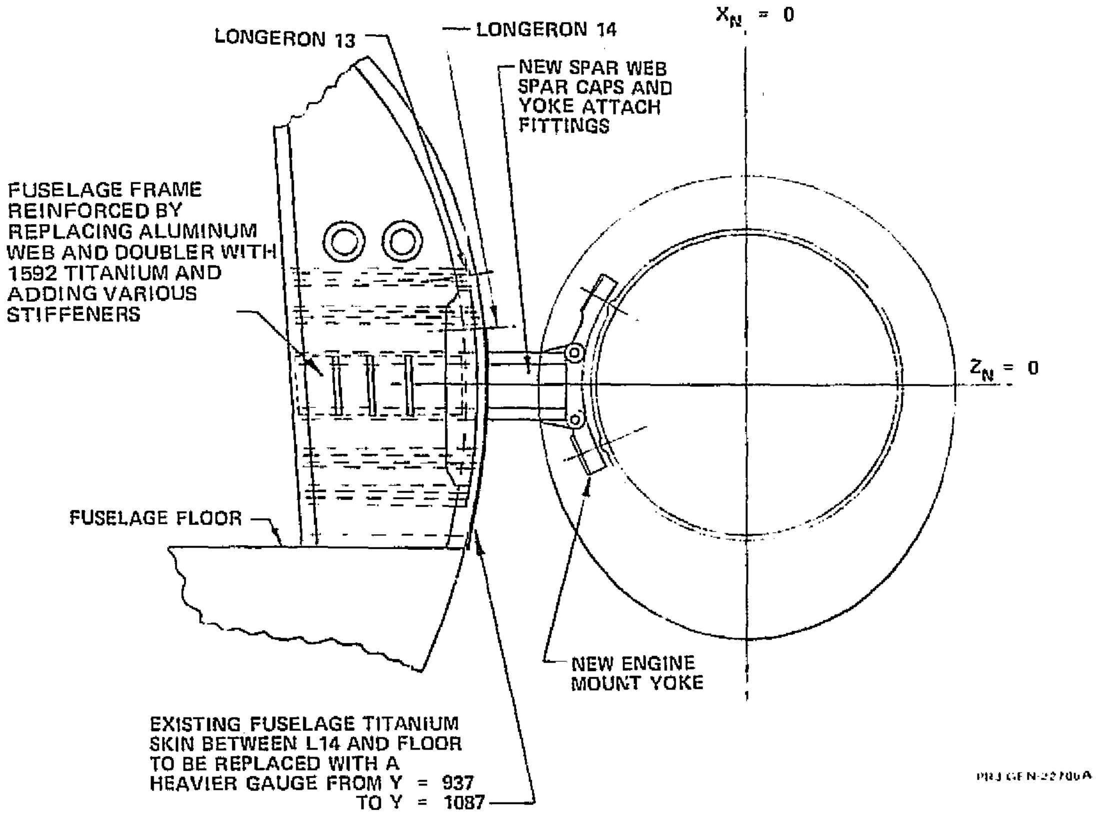

FIGURE 20. FORWARD MOUNT FRAME Y = 965.091

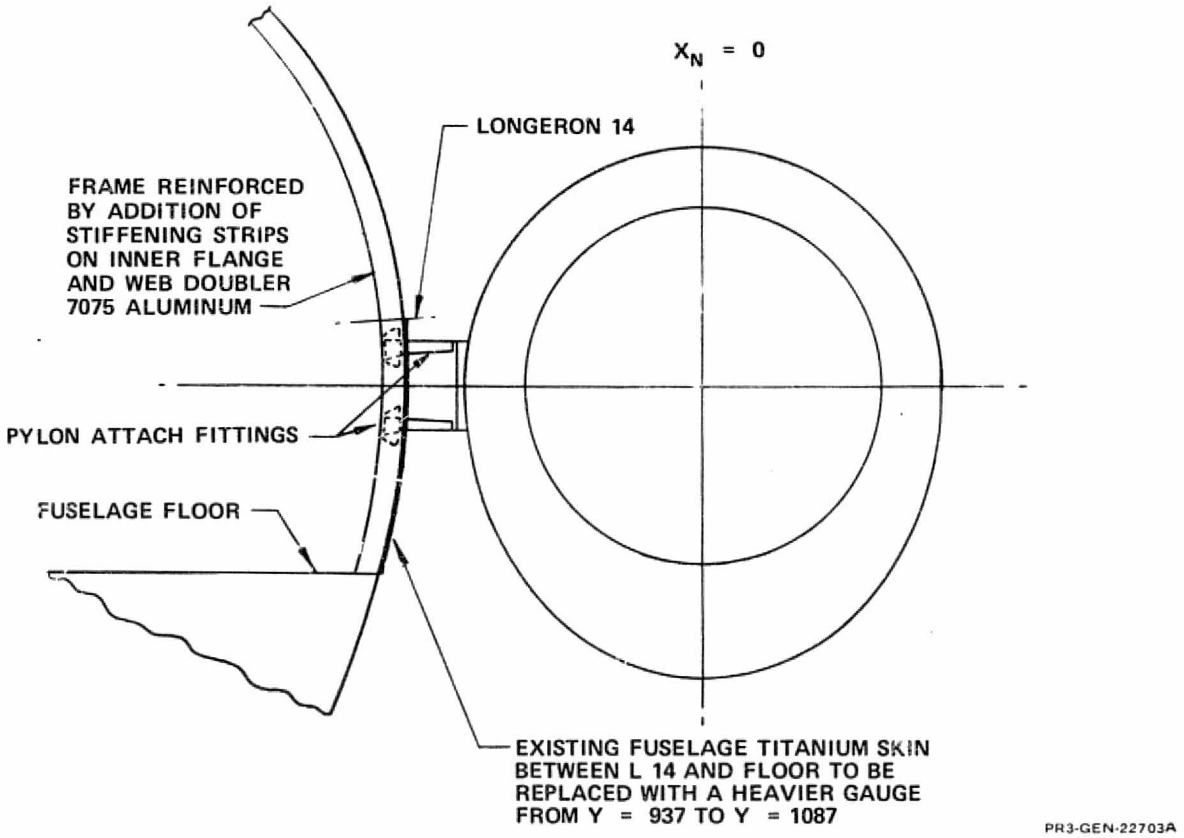

FIGURE 21. TYPICAL FUSELAGE FRAMES Y = 980 AND 1019

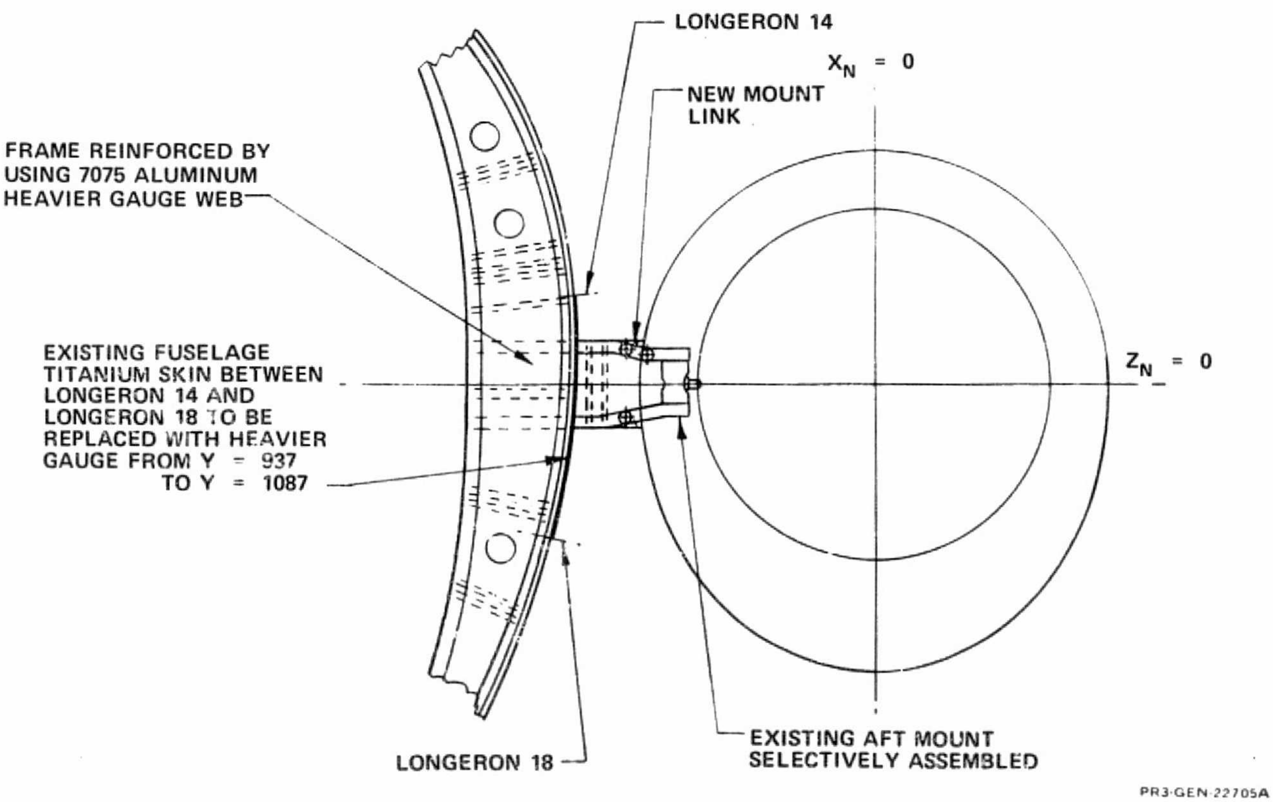

FIGURE 22. AFT MOUNT FRAME

and replacing it with one of a thicker gauge, figure 22. Various stiffeners, reinforcings, and shear clips were then added.

The front and rear spar frames are manufactured in-plant and were modified for the Refan aircraft in their respective assembly areas. The two frames at Y = 980 and Y = 1019 were already assembled to the skin panels when they arrived and were modified at the same time as the skins. The front spar frame at Y = 965.091 is shown in figure 23.

When all the modifications to skins and frames were completed, they were transported with the pylon box structure to position No. 1 on the production line, for assembly to the aircraft. The sequence of assembly was:

- The pylon boxes were attached to the existing modified pylon fuselage joining tools. (See figure 9 and 10).
- The two reworked skin panels were then positioned against the pylon fuselage attach angles.
- The upper unmodified skin panel was attached to the two side panels.
- Finally the fuselage frames, both modified and unmodified were attached in their respective positions. (See figure 24 and 25).

Fuselage keel. - The additional weight of the Refan installation at the aft end of the fuselage, with the fuselage design condition for two wheel landing generate overall fuselage bending loads in excess of the production main fuselage keel design. Therefore it was necessary to reinforce the keel in the main landing gear well area.

The design of the production keel consists of frames and ribs fitted to the inside of the door jamb members and skin. In order to make changes on a retrofit basis without substantial modification of existing parts, nested straps and channels were added to the face of the door jamb members and an external doubler added on the surface of the lower skin. These modifications were incorporated between fuselage stations Y = 598 and Y = 756. The material used for the keel reinforcing is shown in Figure 26.

The keel is manufactured in plant and was modified for the Refan aircraft in its assembly area. The lower skin is shown in figure 27 and the keel in figure 28. When modification was completed, the keel was taken to the production line and assembled to the fuselage in the normal line position, figure 29 and 30.

Forward fuselage. - The additional weight of the Refan engine installation at the aft end of the fuselage made it desirable, for certain minimum payload operations, to add ballast trays at the forward end to maintain the c.g. within the certifiable limits.

Investigations were made to see if the ballast installation on the DC-9-30 aircraft, which consists of a tray on either side of the nose wheel well capable of installing a total of 318 kg (700 lb.), would be

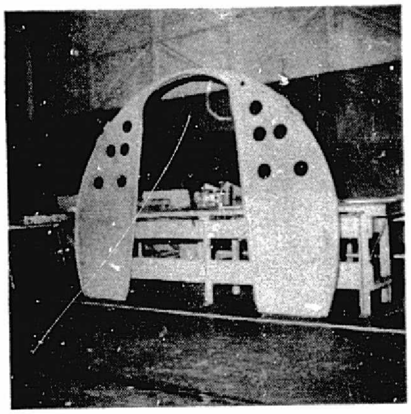

FIGURE 23. FUSELAGE FRONT SPAR FRAME AT Y = 965.091

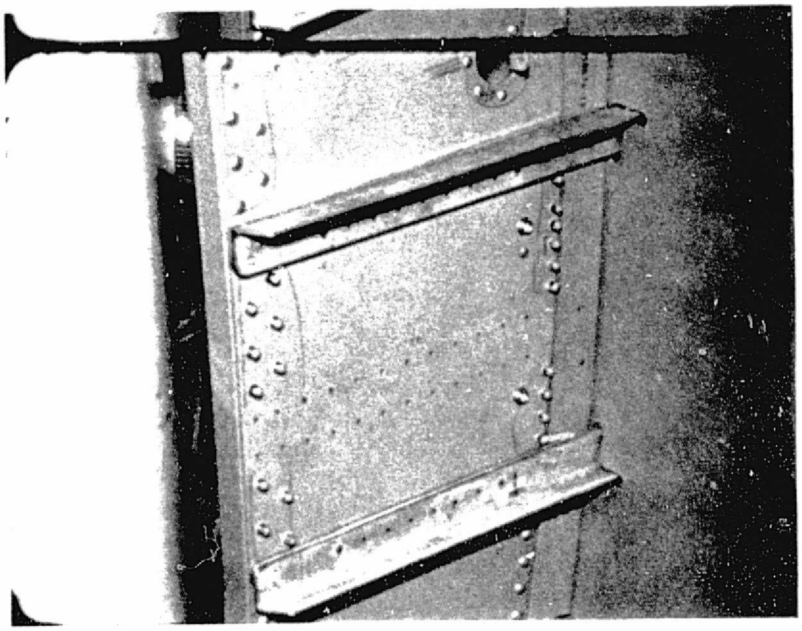

FIGURE 24. REAR SPAR FRAME AND PYLON CAPS INSIDE FUSELAGE

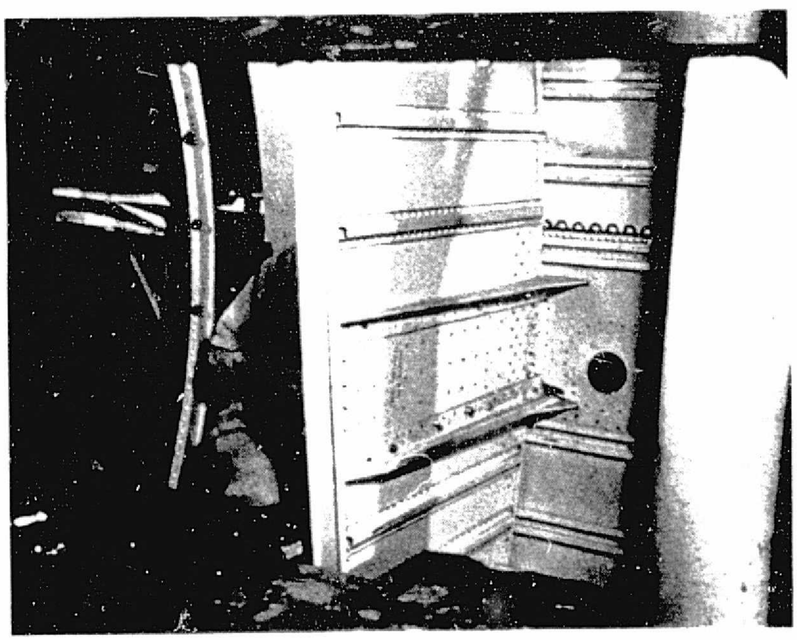

FIGURE 25. FRONT SPAR FRAME AND PYLON CAPS INSIDE FUSELAGE

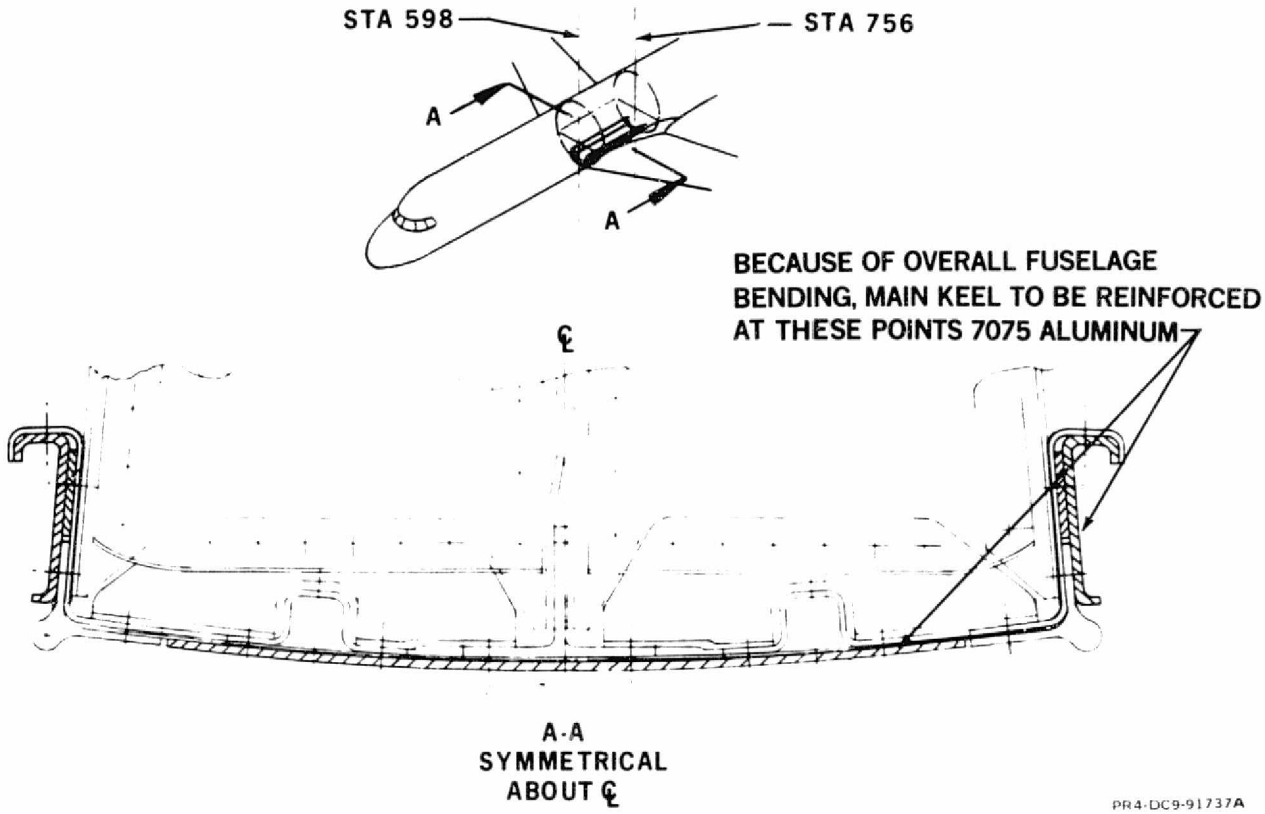

FIGURE 26. FUSELAGE KEEL REINFORCING

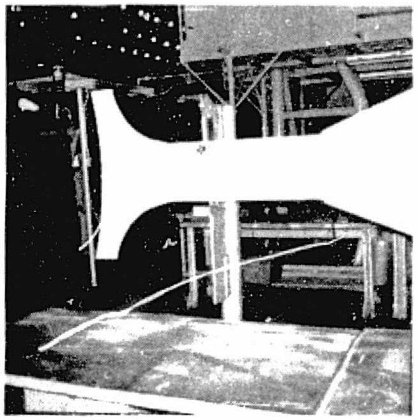

FIGURE 27. FUSELAGE KEEL – LOWER SKIN

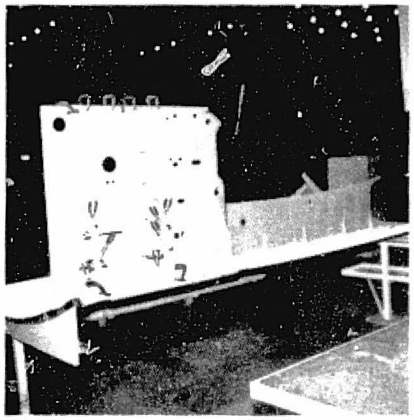

FIGURE 28. FUSELAGE KEEL

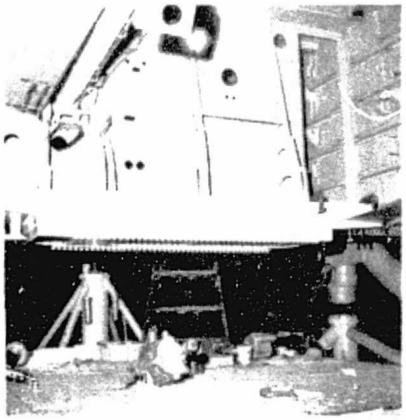

FIGURE 29. FUSELAGE KEEL ASSEMBLED TO AIRCRAFT

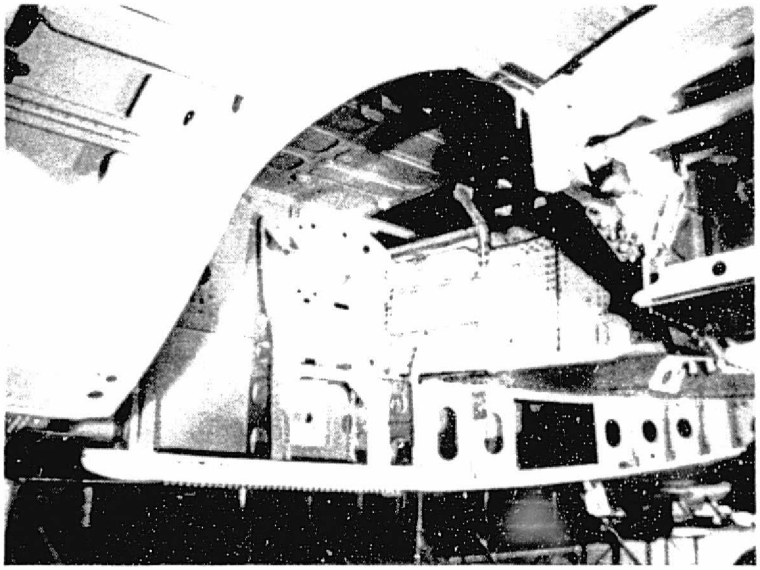

FIGURE 30. FUSELAGE KEEL AT WING JOINING

adequate for the Refan aircraft. It was found desirable to add an additional tray, figure 31.

During flight testing twelve seats were installed in the forward cabin of the aircraft, therefore the ballast trays were not used and were replaced by pallets and weights installed on the forward cargo area.

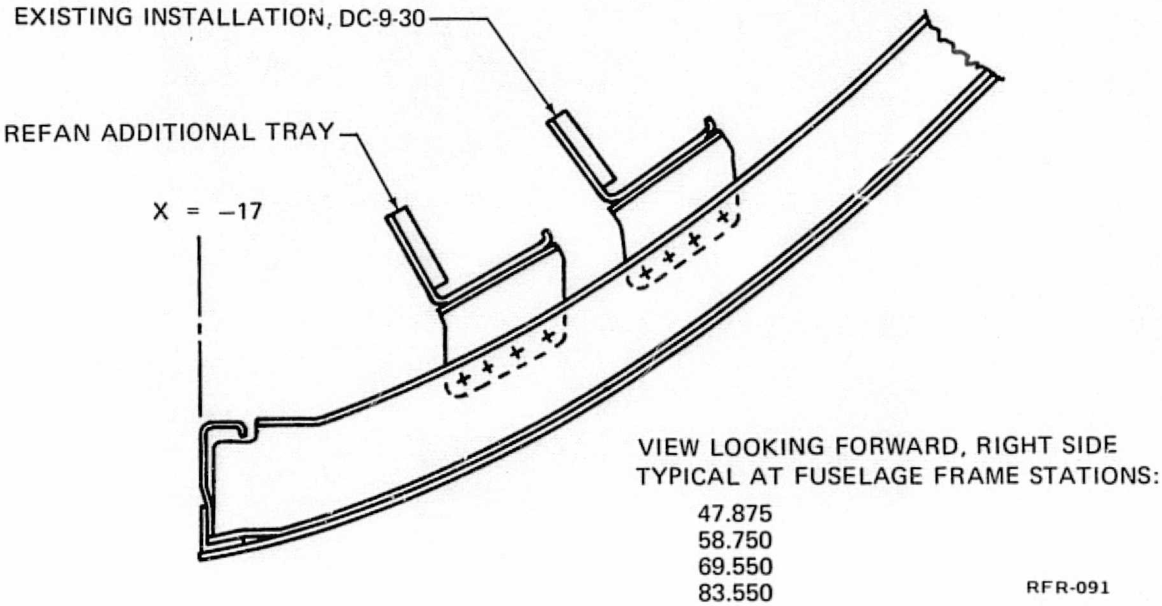

FIGURE 31. PROPOSED FUSELAGE BALLAST INSTALLATION

Engine Mount System

The mount system for the Refan installation was unchanged in concept to the production design with many of the existing components used.

The production engine mount system is a three point system, figure 32, utilizing an upper and lower mount at the forward end of the engine and one mount on the engine horizontal centerline at the aft end. The three attachments are made by cone bolts installed on the engine flanges and mated to the mount isolators.

The airframe mount structure, figure 33, was composed of a front mount yoke into which 2 isolators are mounted, one at the upper and one at the lower end, and an aft isolator attached directly to the pylon.

The forward isolator, figure 34, consists basically of an outer housing and an inner boss. The inner boss was cushioned from the outer housing by means of a number of woven wire pads positioned at the top and bottom and also radially. The outer housing fits into a pocket in the mount yoke and the engine mounted cone bolt mates with the inner boss.

The aft isolator, figure 35, works on the same principal as the forward, except that the outer casing attaches directly to the pylon rear spar by means of links, the lower one being integral with the outer housing and the upper being separate.

Production type tuned vibration absorbers, figure 33 and 34, installed on the forward mount yoke were developed for reduction of cabin noise induced by rotor vibration. They consist of heavy metal weights mounted on the end of small pins or beams. These beams are screwed into the ends of the forward yoke mount bolts.

There are no tuned vibration absorbers on the aft mount.

Forward engine mount. - Because of the larger and heavier engine, it was found that the production front mount yoke, manufactured from a hi-tuf steel die forging, was not of sufficient strength to take the higher loads. As there was not enough material in the production die forging from which to machine the larger component required for Refan, various trade studies were made taking into account cost, availability, and strength of material. It was concluded from the studies to manufacture the yoke from a 300 m steel hand forged billet. Each billet on delivery weighed 340.19 kg (750 lb.) and was machined to a finished weight of 19.05 kg (42 lb.).

The forward isolators had a marginal service life strength, therefore two units were selectively assembled for this aircraft. The various detail parts in the unit were chosen with a plus tolerance, thereby giving a satisfactory service life.

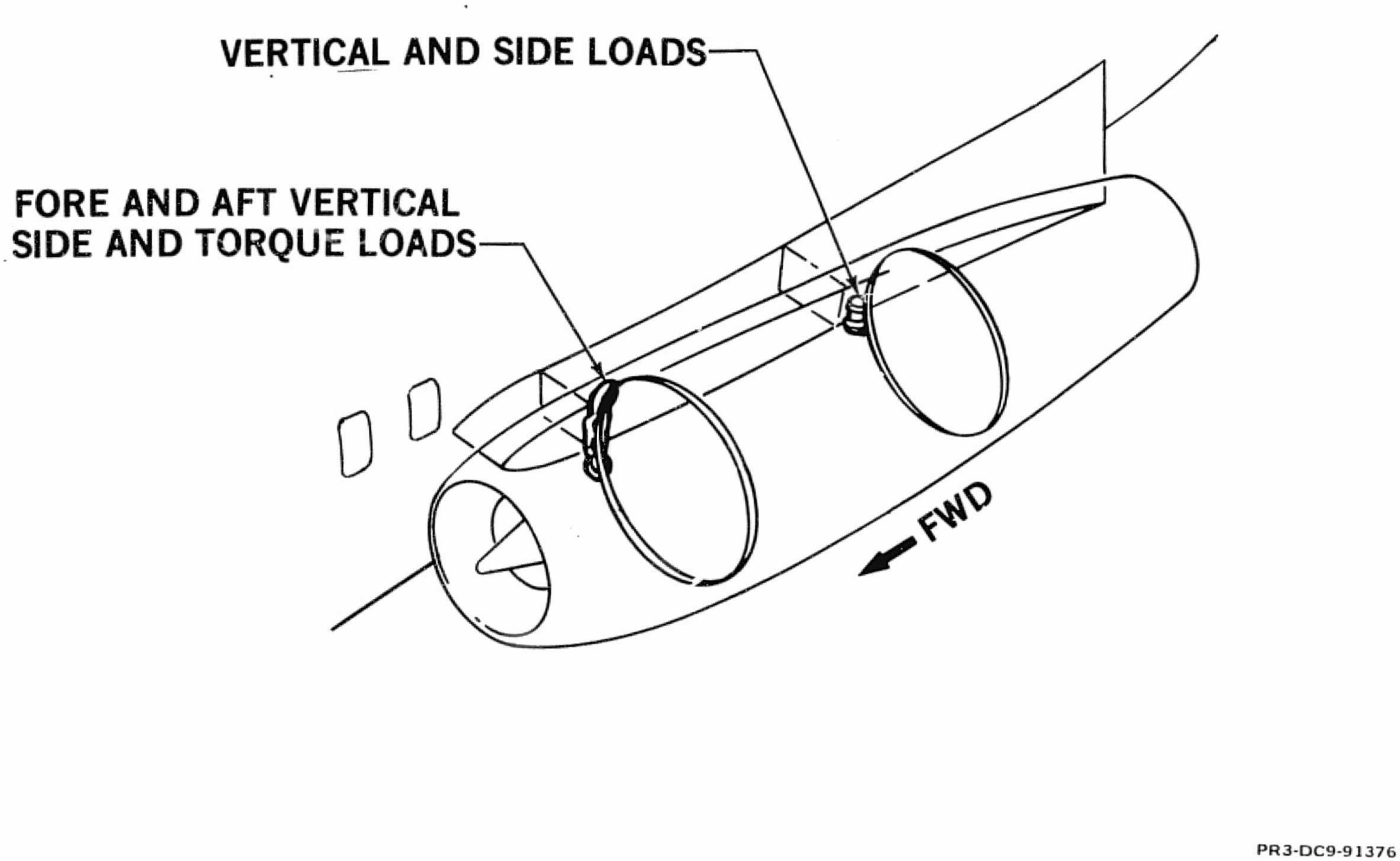

FIGURE 32. ENGINE MOUNT SYSTEM

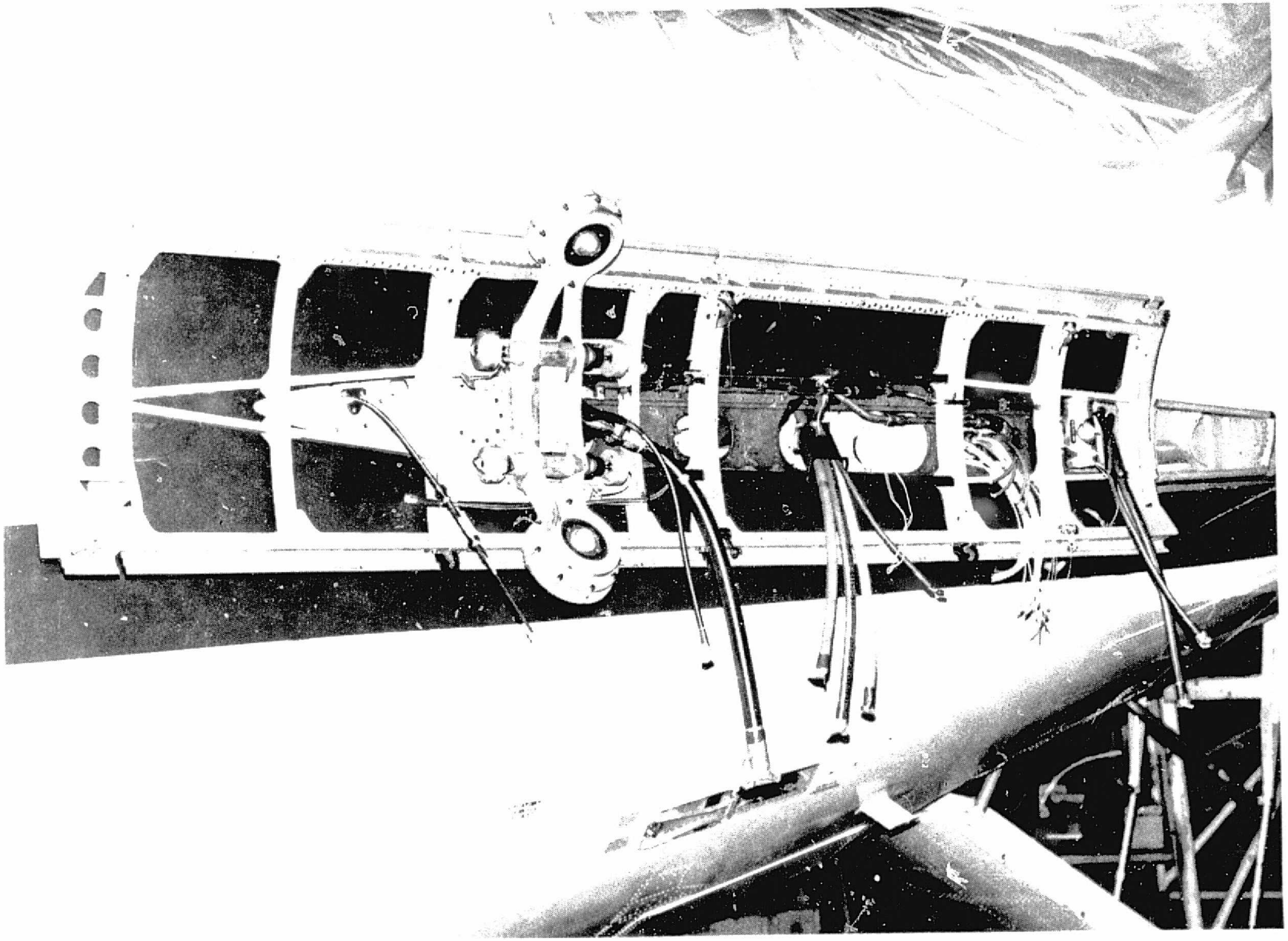

FIGURE 33. FORWARD AND AFT ENGINE MOUNTS AND APRON

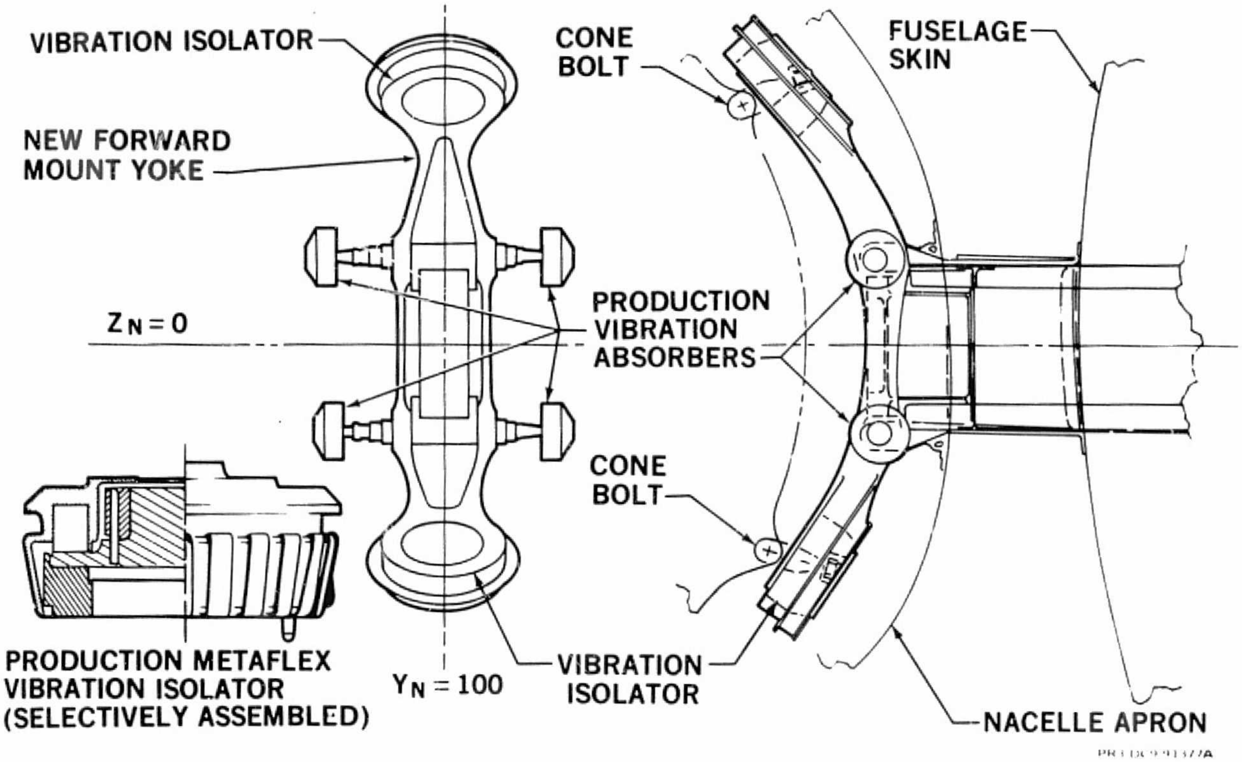

FIGURE 34. DC-9 REFAN JT8D-109 ENGINE MOUNT VIBRATION ABSORBERS AND ISOLATORS

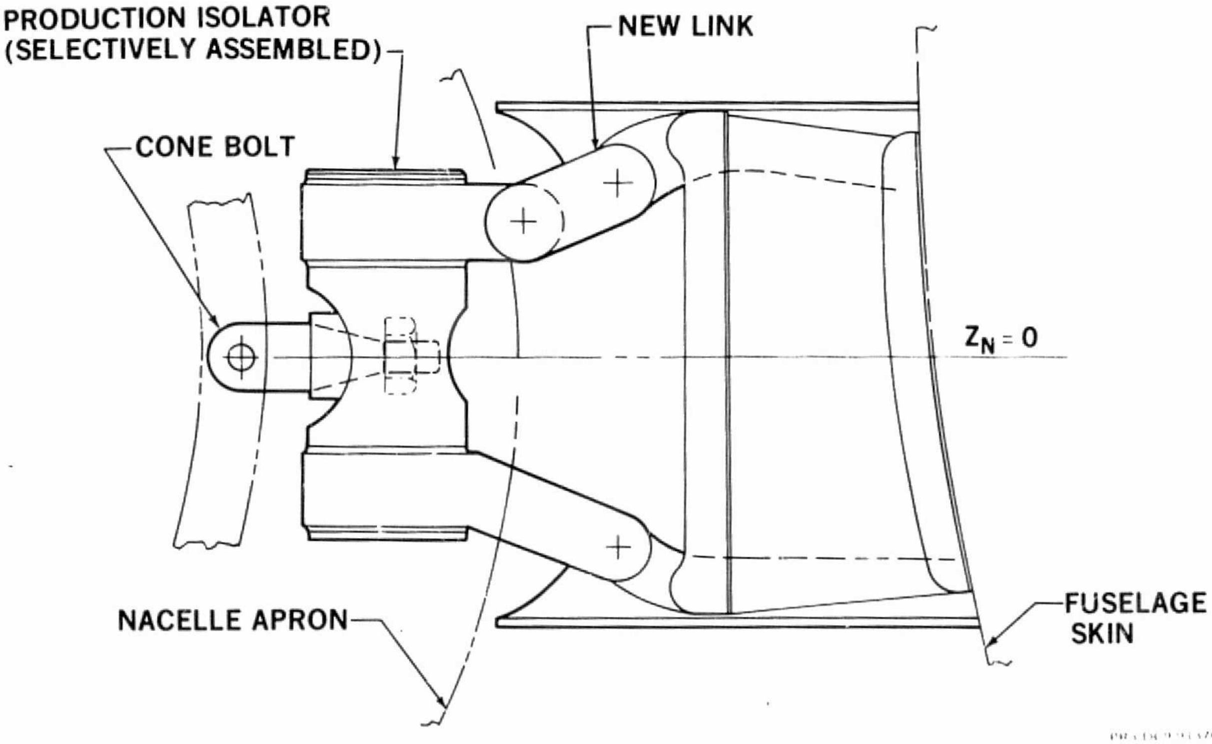

FIGURE 35. DC-9 REFAN JT8D-109 ENGINE AFT MOUNT AND VIBRATION ISOLATOR

The production type tuned vibration absorbers are used on the prototype Refan aircraft on a restricted flight demonstration basis. If the cabin noise level proves to be unacceptable during flight demonstration, a vibration absorber development program would be required.

<u>Aft engine mount</u>. - The aft isolator was basically the same as production, but the various detail parts in the unit were chosen with a plus tolerance, in order to meet the higher loads imposed on them. The upper attachment link for the unit was redesigned to take the higher loads.

The front mount yoke was machined in-house and assembled to the pylon in the Flight Development Center.

Nacelle Construction

The Refan nacelles were designed to achieve the desired noise suppression goals with the JT8D-109 engine, yet retain the existing DC-9 airplane installation concept.

The nacelle configuration incorporates acoustic treated material in the inner surface of both the nose cowl and the tailpipe. This design retains the "long duct" concept with mixed primary and fan air exhaust.

The Refan nacelle shown in figures 36, 37 and 38 required a new nose cowl and bullet, new upper and lower access doors, new pylon aprons, and a new exhaust duct and thrust reverser.

Nose cowl. - The Refan nose cowl shown in figure 39 was configured symmetrical about the centerline for interchangeability with the left and right hand side. The nose lip was designed with an increased thickness ratio from the production, using DC-10 technology, to prevent separation. The inlet area was sized for the flow requirements of the JT8D-109 engine with growth. A trade study in Phase I resulted in a design of an increased length inlet without rings.

The nose cowl basic structure consists of an inner barrel, outer barrel, nose lip/D-duct assembly and an aft closing bulkhead.

The inner barrel, as shown in figure 40 in the assembly tool, was the principal structural member of the nose cowl. All nose cowl loads were transferred into the engine case by means of a flange at the aft end of this inner barrel which attaches to the front ("A") flange of the engine with 24-7.92 mm (.312 in.) dia bolts. The construction of the inner barrel acoustic treatment (figure 41) was bonded aluminum honeycomb sandwich. The face sheet on the wetted surface .64 mm (.025 in.) in thickness perforated with 1.27 mm (.050 in.) diameter holes in a pattern that provides an open area of 6.4%. The solid back face sheet was .51 mm (.020 in.) in thickness. The core cells are 9.52 mm (.375 in.) hexagons with walls .076 mm (.003 in.) thick. Drain holes are provided in the core walls to prevent damage due to freezing of trapped moisture. The core height (cell depth) was 14.22 mm (.560 in.). The inner barrel is split into three identical 120° segments with a longitudinal splice member and mechanical attachments at each joint. See figure 41. This follows the concept used on the treated inlets of DC-9 and DC-10 aircraft that permits the replacement of a damaged portion of an inlet inner barrel without requiring replacement of the entire inner barrel.

The outer barrel shown in figure 42 is of conventional 2024 aluminum skin and zee shaped stiffener construction. The skins were stretch formed into three pieces split 30° above the horizontal centerline and at the bottom centerline. Removable panels for access to the ice protection piping and an exit louver for ice protection exhaust air were located along the lower centerline. Hoist pickup points were provided at four locations in the upper region of this structure.

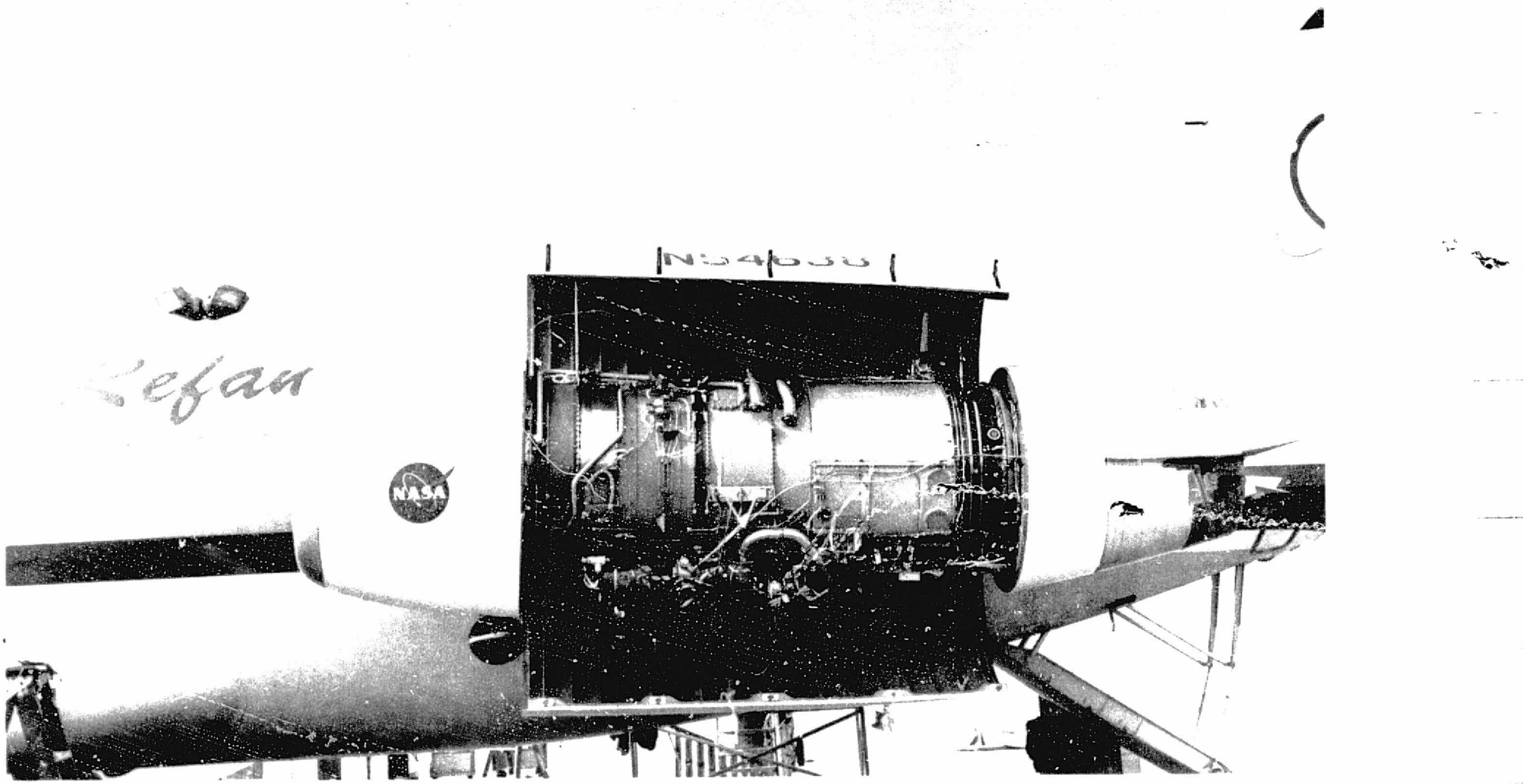

FIGURE 36. LEFT ENGINE INSTALLATION

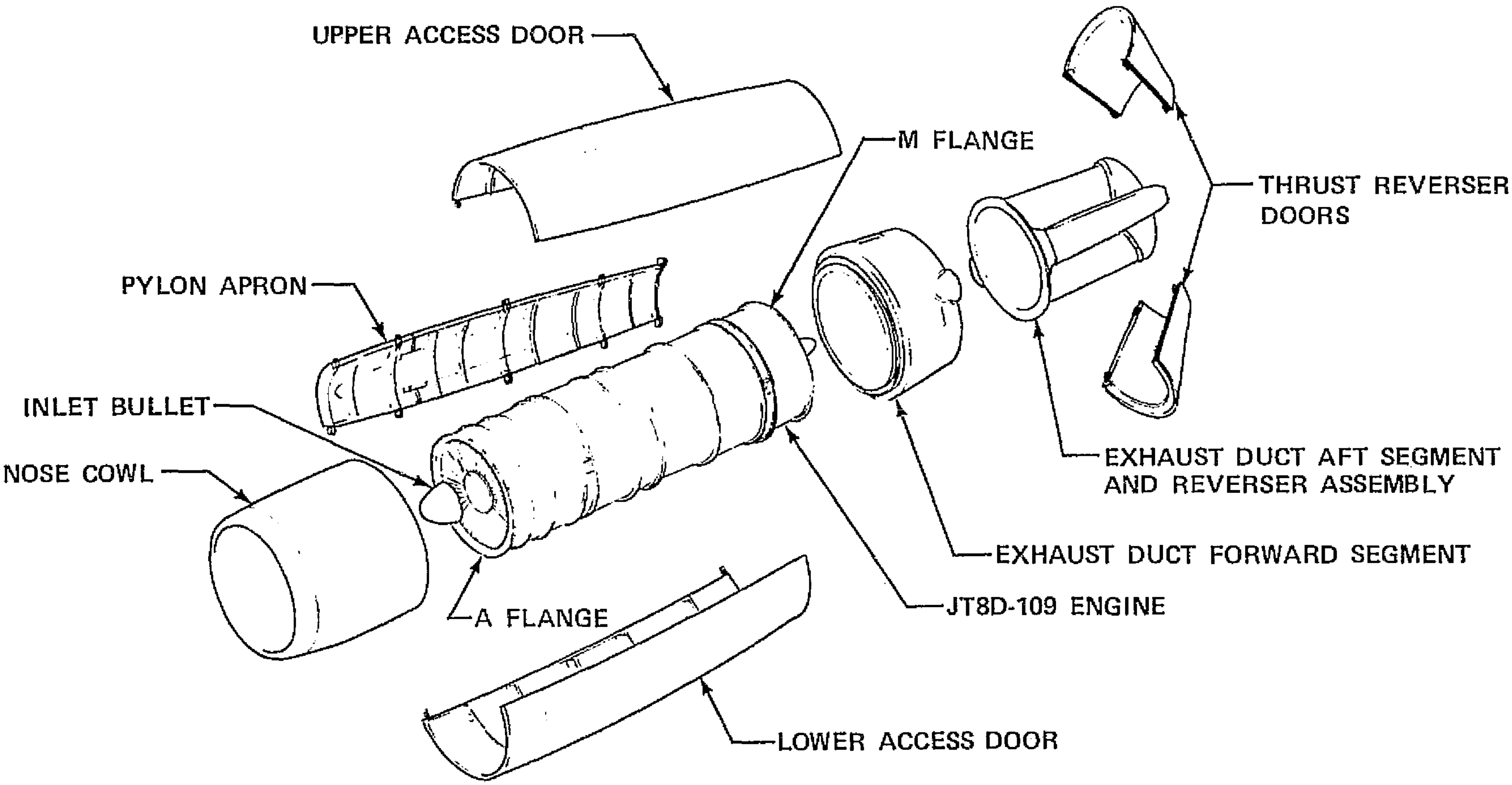

FIGURE 37. DC-9 REFAN NACELLE HARDWARE

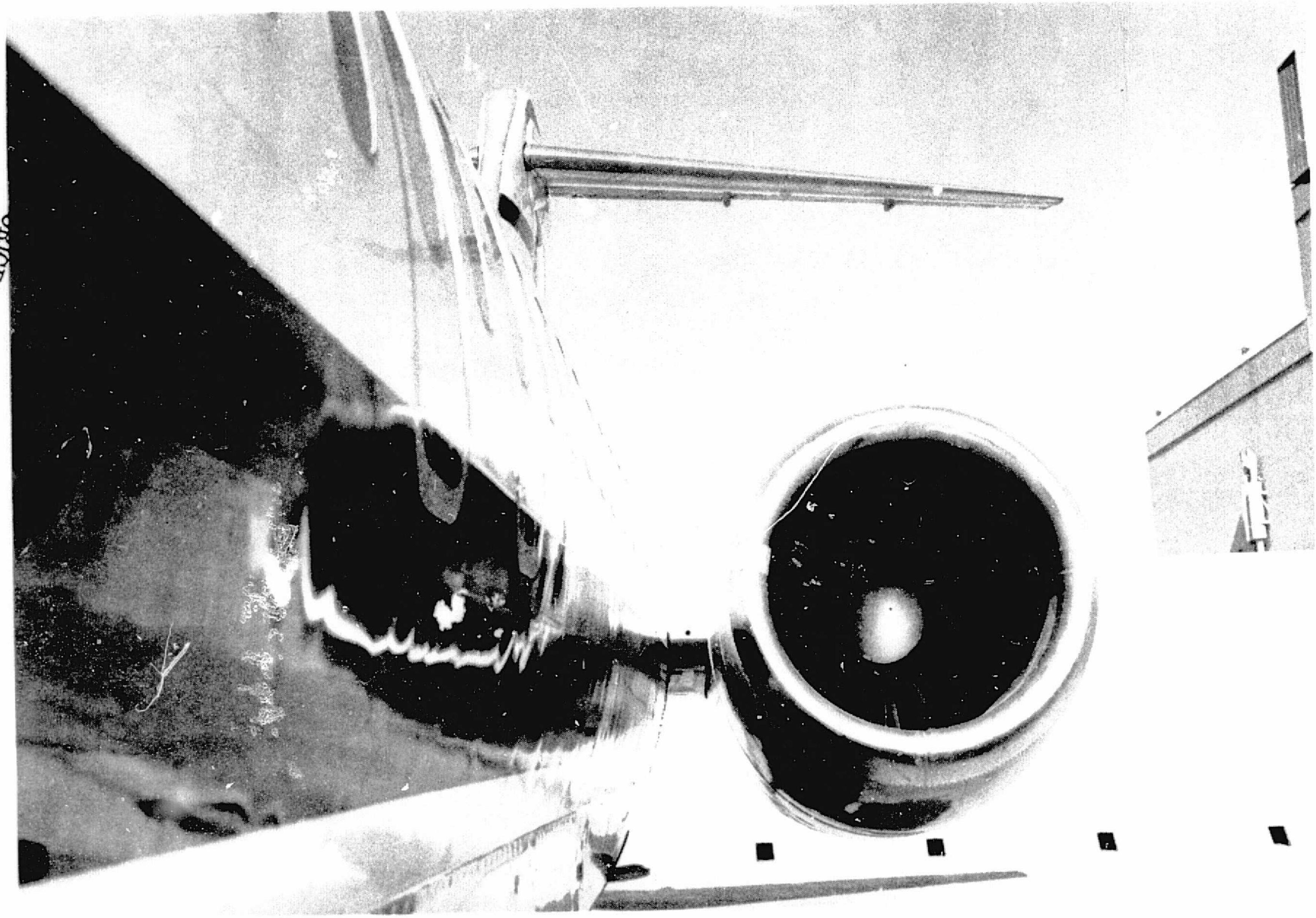

FIGURE 38. LEFT NACELLE AND PYLON – FRONT VIEW

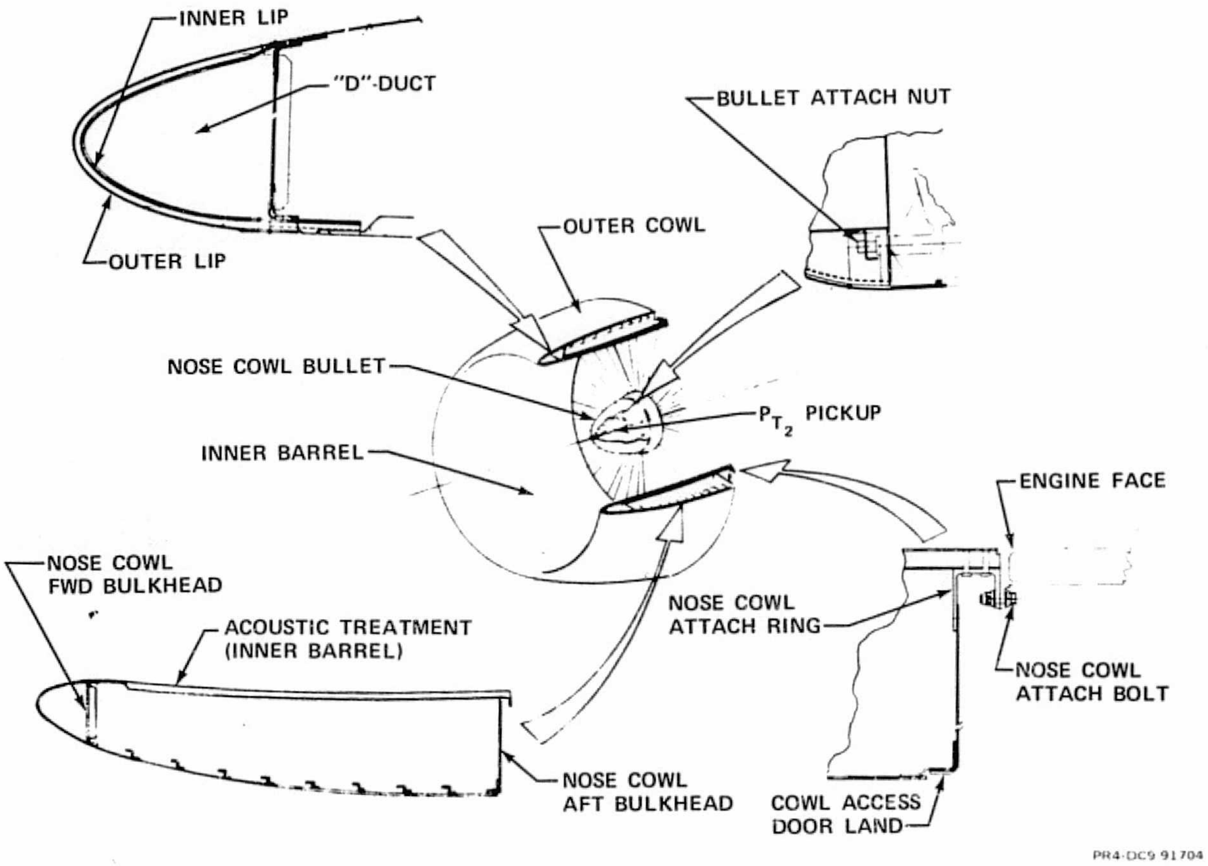

FIGURE 39. NOSE COWL STRUCTURE

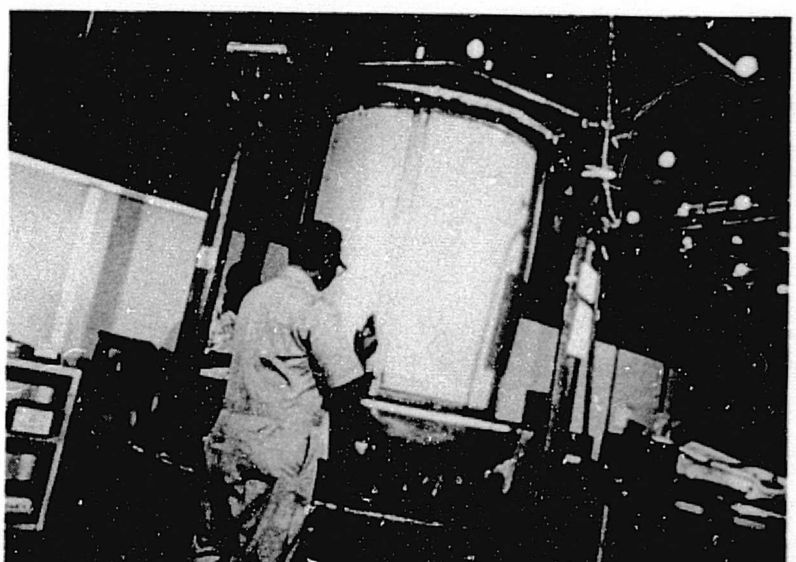

FIGURE 40. NOSE COWL INNER BARREL IN ASSEMBLY TOOL

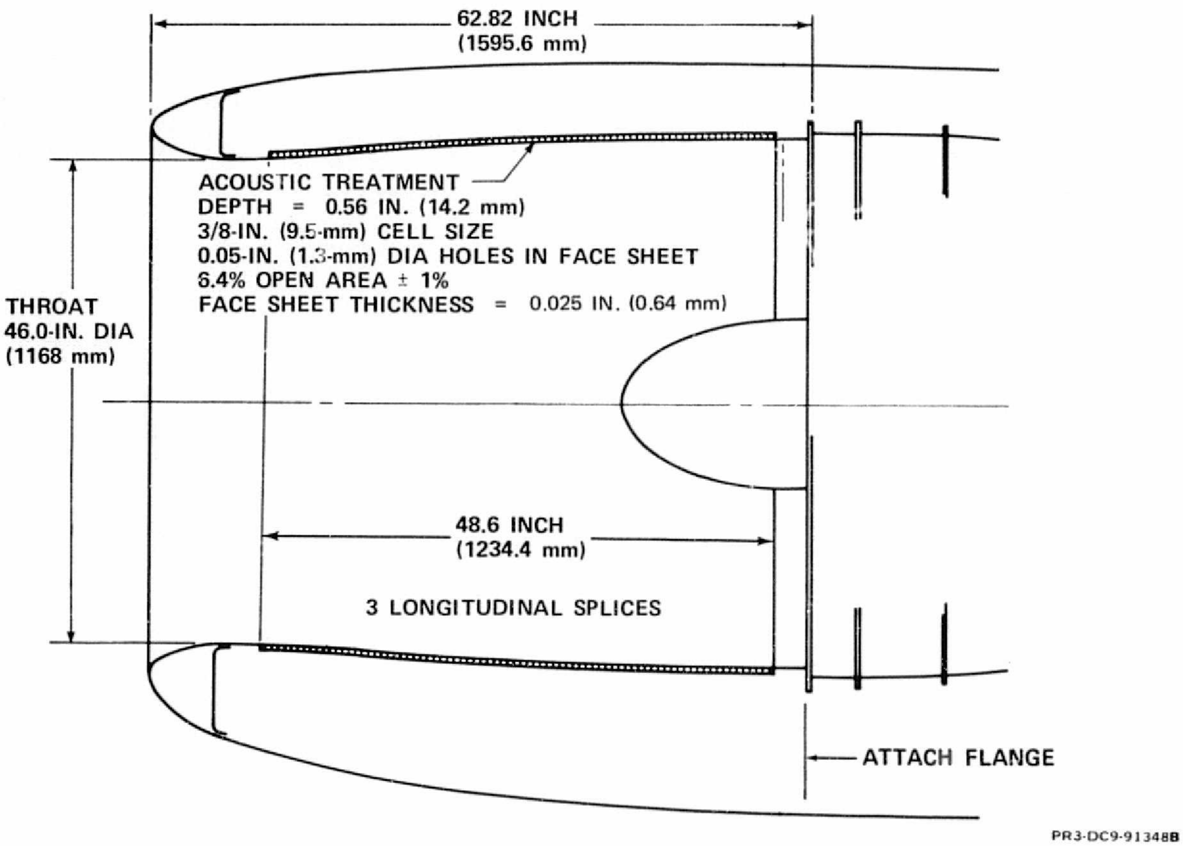

FIGURE 41. INLET DUCT – ACOUSTIC TREATMENT

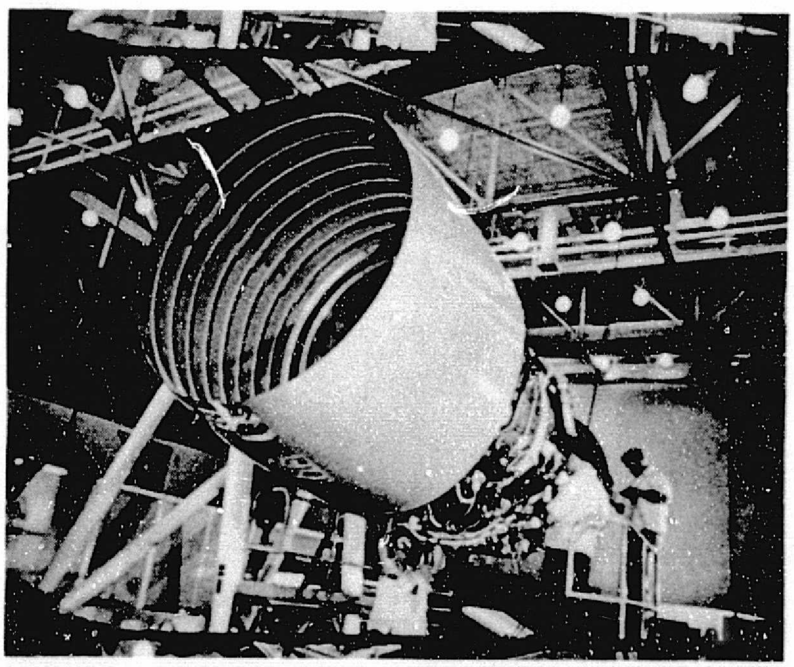

FIGURE 42. NOSE COWL OUTER BARREL

The nose lip/D-duct assembly also shown in figure 39 consists of a 2219 aluminum outer lip and inner lip, between which the anti-icing air passes, and a bulkhead constructed of titanium and corrosion resistant steel. A 2219 aluminum flow metering plate between the inner and outer lips completes the list of principal elements of this assembly.

The titanium aft bulkhead of the nose cowl forms the load path for supporting the outer barrel from the inner barrel. This member also creates the firewall at the forward end of the pod. The outer periphery of this bulkhead incorporates a land for the leading edge of the access doors and apron. Fittings located on the aft face of the bulkhead react loads imposed by the apron.

The 2219 aluminum inner and outer lips were drop hammer formed in four pieces each, split at the horizontal and vertical centerlines. The outer lips were welded at each joint; the inner lips were mechanically spliced. In order to maintain the prescribed gap and trim lines between the lips, the flow metering orifice, and the forward bulkhead, the parts were subassembled into a plaster cast. Temporary spacers were used to establish and maintain the proper gap so that skin trim, rivet attachments and the forward bulkhead could be properly located. Before mating to the inner and outer barrels, the unit was bench flow checked.

Inlet bullet. - The inlet bullet shown in figure 39 was an aerodynamic fairing mounted on the forward face of the engine inlet. The design was identical to the DC-9, but larger in diameter and length to fit the JT8D-109 inlet case. It was fabricated from 6061 aluminum and consisted of an aft cone and forward dome separated by a 360° annular slot.

The engine air inlet pressure P_{T2} probe was contained within the bullet and its inlet was concentric with and protrudes thru the forward dome. A connection at the inlet case was supplied for continuation of the P_{T2} line run.

Five engine studs, one of which was offset, were provided for installation of the bullet. This non-symetrical attach arrangement assures that as the bullet was installed, the P_{T2} "O" ring sealed slip joint connection was made.

Inlet guide vane (IGV) anti-icing air enters the bullet thru holes provided in the engine case. This air flows forward to heat the forward dome, then exits thru the annular slot.

The inlet bullet is identical and interchangeable on both the left and right engines.

Nacelle access doors. - The increased size of the JT8D-109 engine required increased length and diameter doors and aprons. The two access doors were hinged at the inboard side of each nacelle to the apron and latch together along a flush seam on the outboard side of the nacelle. Small access doors were provided in the lower door for servicing the engine oil tank, the CSD, and the starter. See figure 43.

The doors were identical in design concept to the DC-9 production articles and consist of five hinge/latch frames, leading and trailing edge

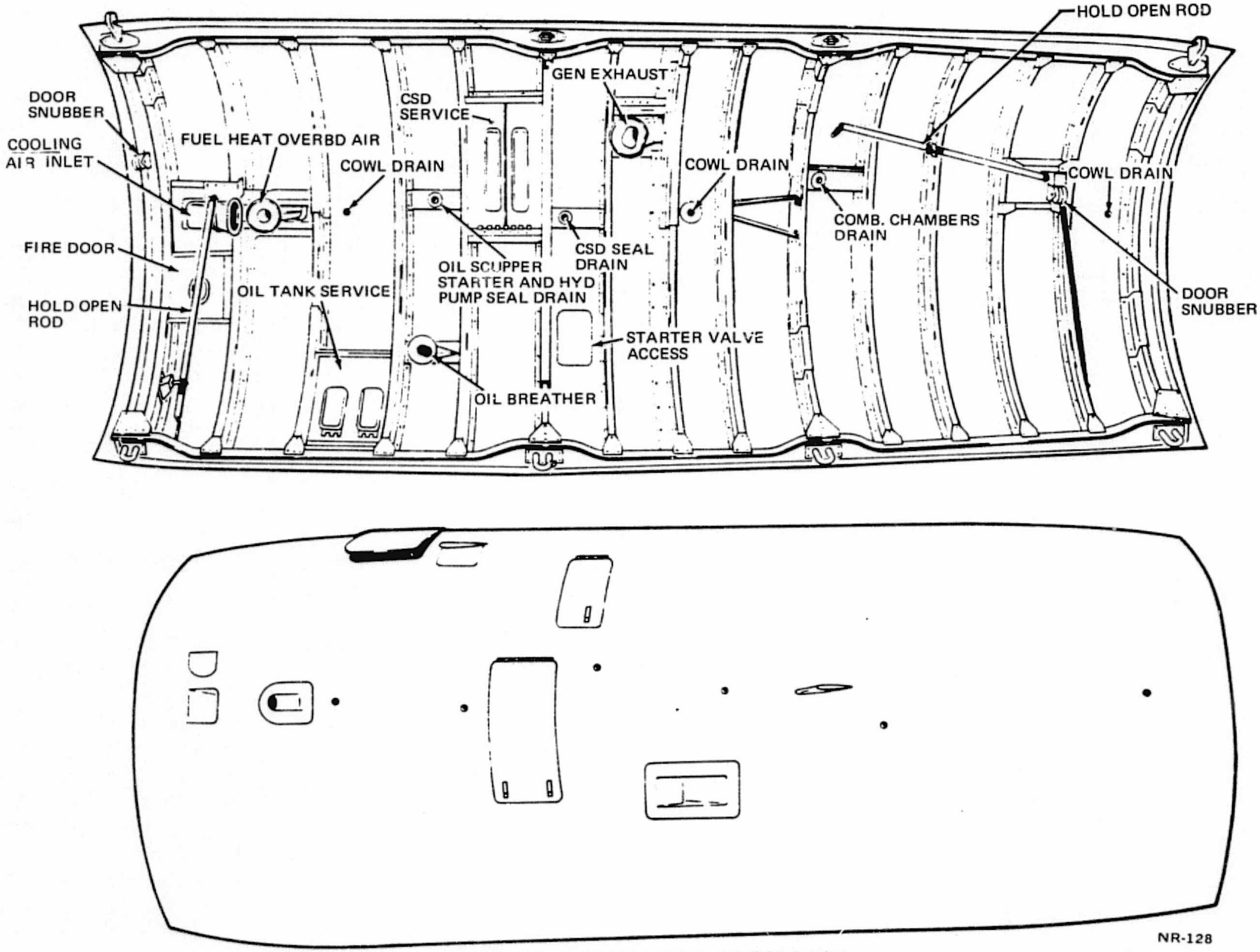

FIGURE 43. ENGINE LOWER ACCESS DOOR

closing frames and upper and lower longerons. Three intermediate frames between each hinge/latch frame are provided to give the same approximate spacing as on the DC-9 production doors. The existing DC-9 latches are used. See figure 44.

The skins were stretch formed using existing form dies with removable plastic built-up faces to form the multiple skins with double contour. The zee frames were brake formed prior to stretch forming to contour. Hydro forming was used for the closing stringers. An assembly jig was required for each of the four doors (left-hand and right-hand).

Pylon apron. - The apron structure forms the aerodynamic interface between the nacelle and the pylon. It was attached to the engine at six locations, two at the nose cowl, two at engine flange H, and two at engine flange K. The aprons were tooled and fabricated in the same manner as the doors requiring hydro forming, brake forming, and stretch forming to contour. A separate assembly jig was required for each apron. See figure 45 for structure comparison.

Exhaust system. - The exhaust duct was configured to provide sufficient area for the sound absorbing material to meet the noise requirements balanced with the inlet treatment and to provide a minimum loss exhaust path. The The aft segment was canted 0.061 radians (3.5°) in lieu of 0.087 (5°) used on the shorter production DC-9 to provide the same aircraft stability. The exhaust duct was interchangeable left hand and right hand with a means of rotating the aft segment and the thrust reverser so as to alleviate reingestion at both engine positions. The exhaust duct provided a load path to transfer the thrust reverser loads into the engine case with structural supports for the thrust reverser actuating cylinder and linkage.

The principal material used in both the forward and aft segment of duct is welded Inconel 625 honeycomb sandwich. The face sheet on the wetted surface shown in figure 46 was .61 mm (.024 in.) thick and perforated with 1.321 mm (.052 in.) diameter holes to an open area of approximately 12%. The solid back face sheet is .406 mm (.016 in.) thick. The core cells are 6.35 mm (.250 in.) hexagons. The core walls are .076 mm (.003 in.) thick. The core height (cell depth) is 8.89 mm (.350 in.). This welded honeycomb sandwich is not vulnerable to water freezing damage so no core drain holes are in the cell walls.

The capability of clocking the thrust reverser is achieved by including a pair of back to back flanges in a location approximately midway along the length of the exhaust duct. The aft segment of the duct shown in figure 47 and 51 contains the structure which accepts the thrust reverser loads by use of a pair of fore and aft beams that feed the loads into the exhaust duct. The trailing edge portion of this aft duct contains a length of outer fairing which aligns with the outer trailing edge surface of the thrust reverser doors. This fairing not only eliminate base drag, but also reacts thrust reverser linkage kick loads.

The forward duct section shown in figures 48 and 49 which attaches to the engine M flange, incorporates bulkheads at the fore and aft ends, to support the outer nacelle fairing. The forward bulkhead was fireproof. The aft bulkhead supports the thrust reverser doors latch mechanisms. The outer

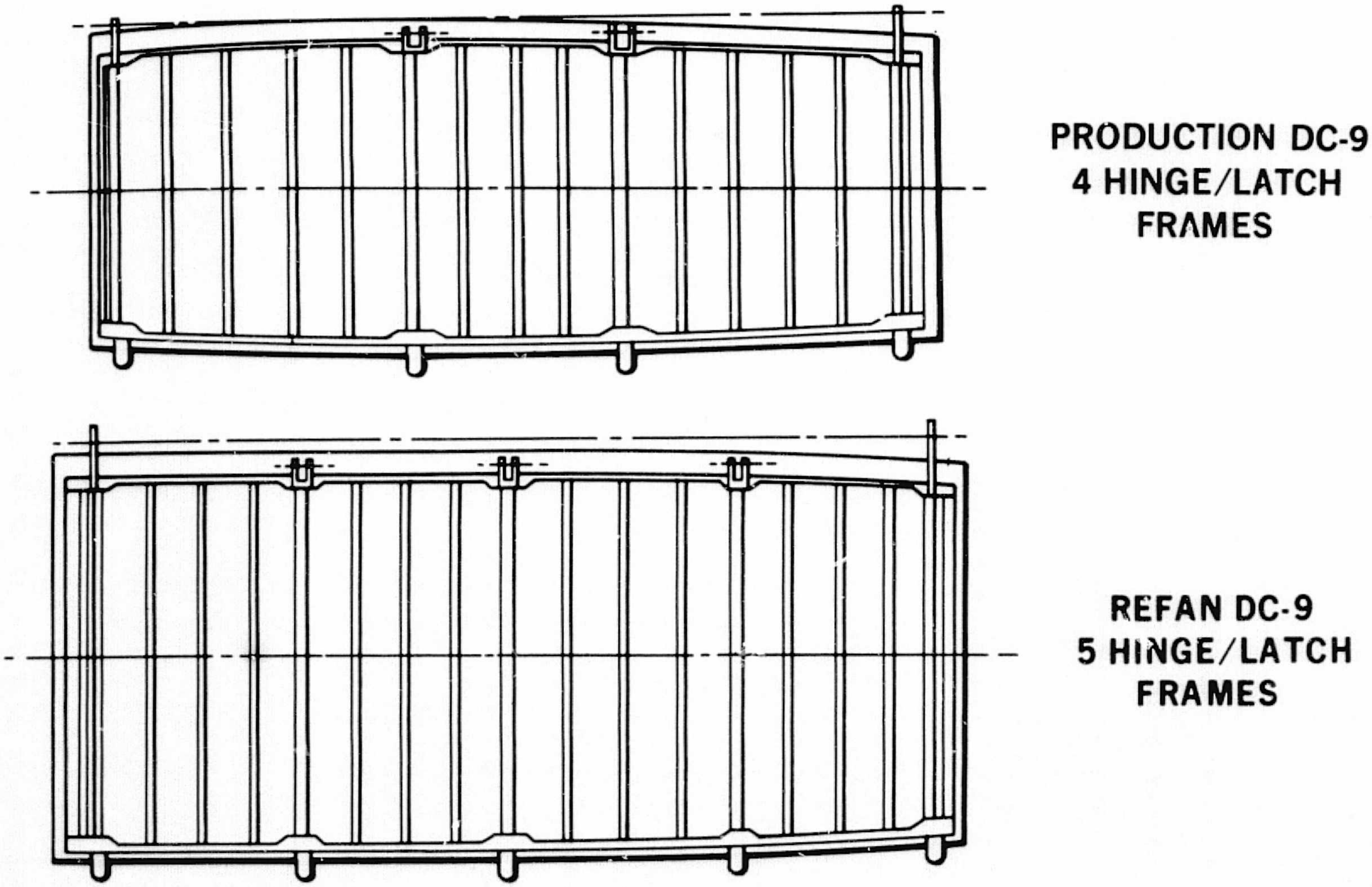

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FIGURE 44. ENGINE ACCESS DOOR COMPARISON

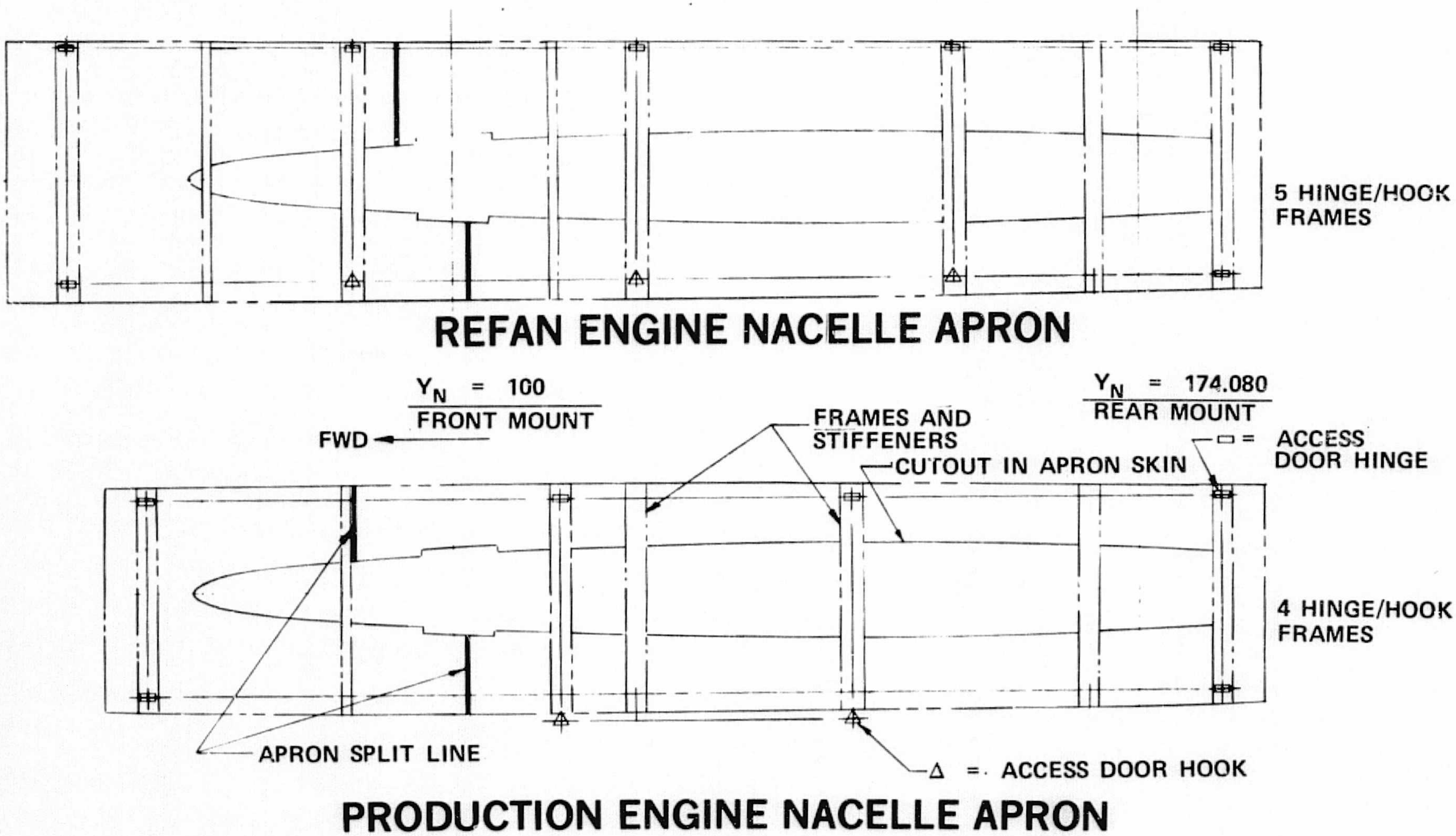

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FIGURE 45. DC-9 REFAN APRON STRUCTURE COMPARISON

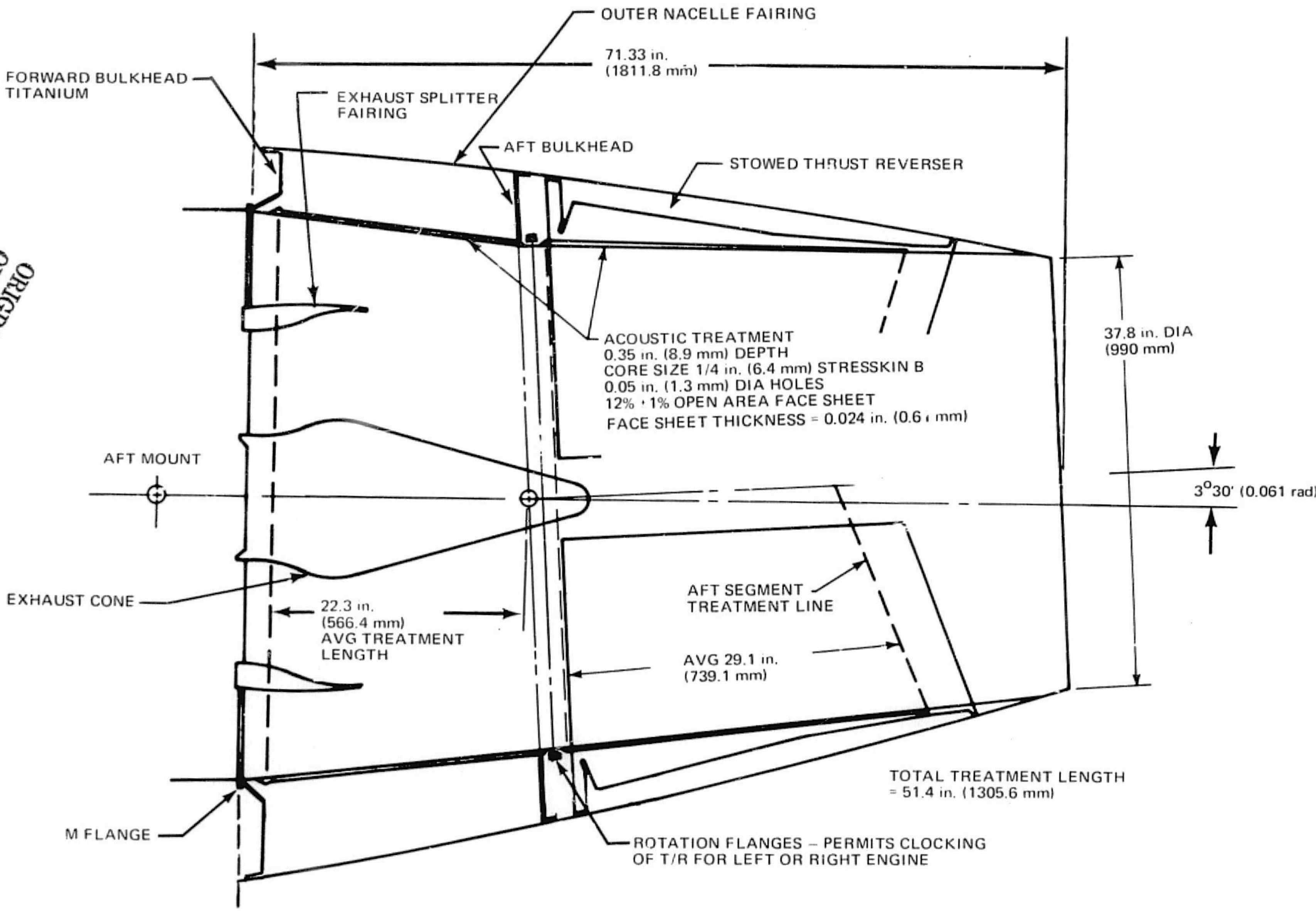

FIGURE 46. DC-9 REFAN JT8D-109 ENGINE EXHAUST DUCT

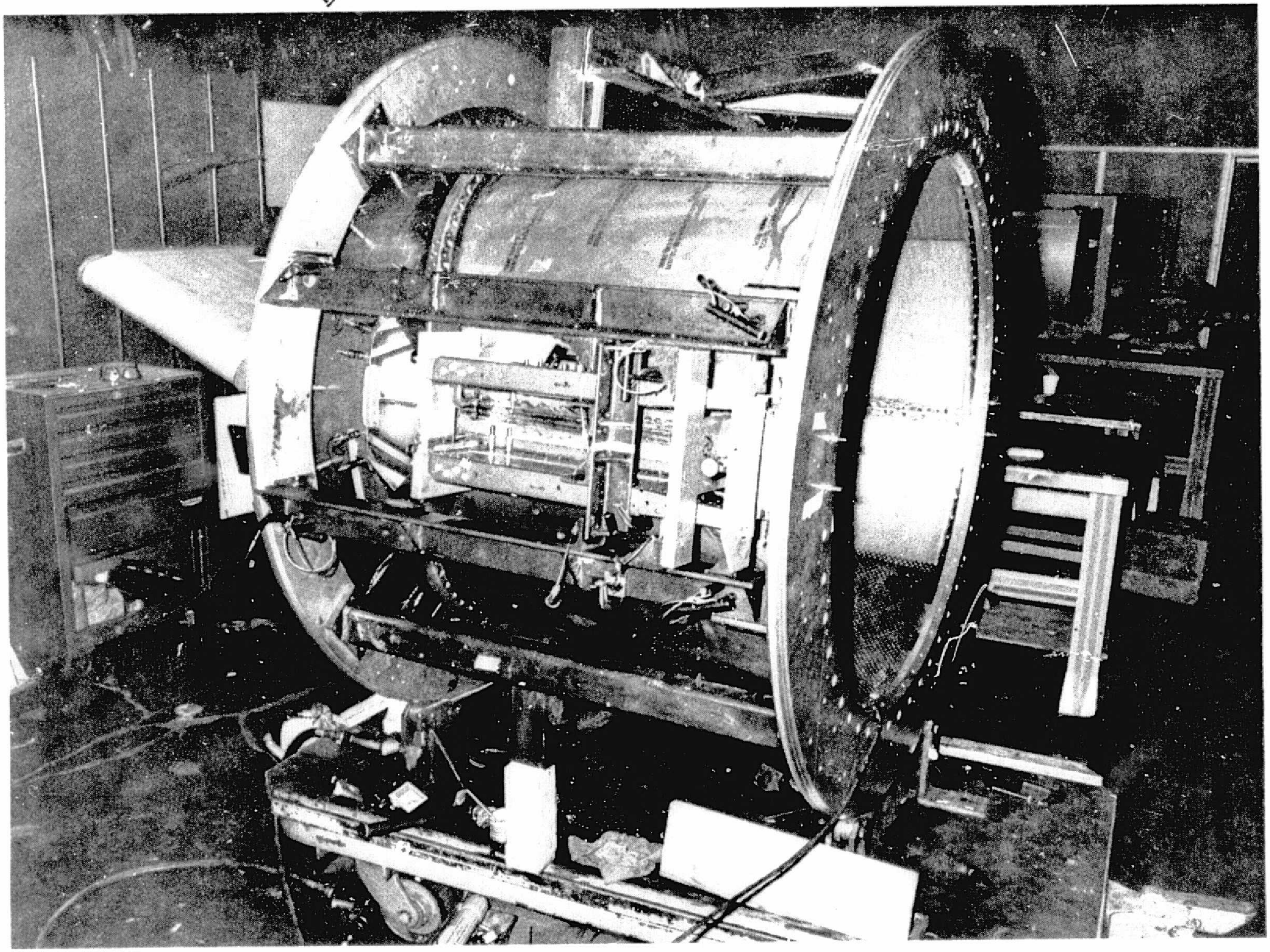

FIGURE 47. AFT SEGMENT – EXHAUST DUCT

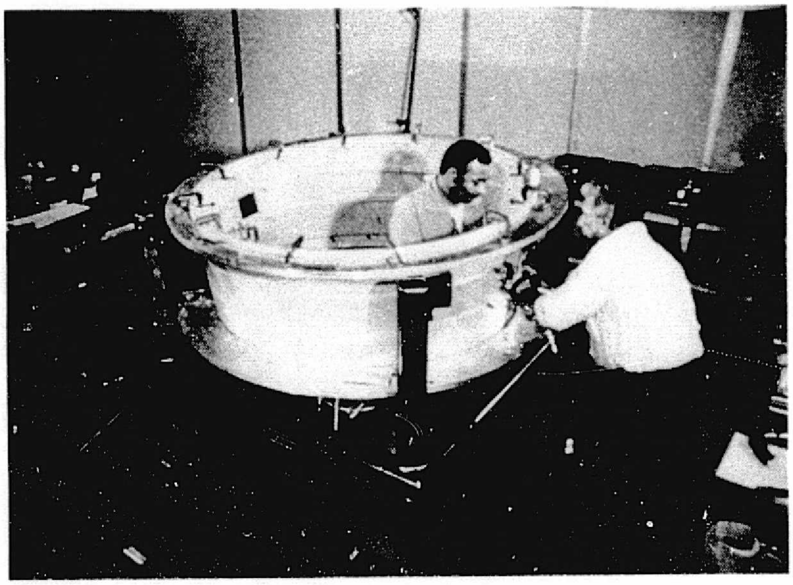

FIGURE 48. FORWARD SEGMENT EXHAUST DUCT

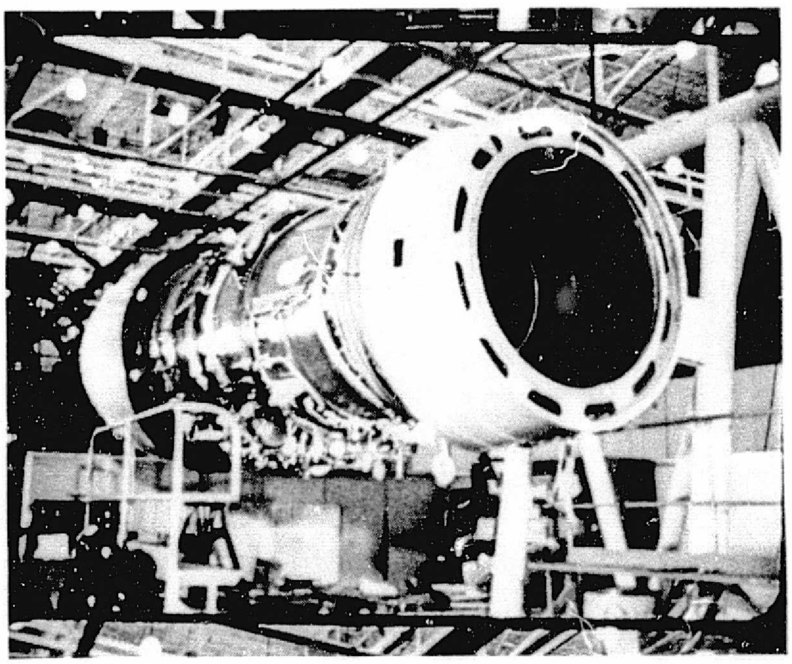

FIGURE 49. EXHAUST DUCT FORWARD SEGMENT ON MOCKUP ENGINE

fairing contains doors for access to the thrust reverser interlock mechanism, hydraulic piping and wiring.

The exhaust system tailcone and splitter shown in figures 46 and 50 are manufactured by Pratt and Whitney. The tailcone allows the exhaust gases from the core to expand with a minimum of thrust loss. The splitter allows mixing of the fan air and core air together inside the tailpipe with a minimum of thrust loss.

The inner barrel of honeycomb sandwich was stretch formed using existing dies with built up plastic faces to match the Refan exhaust duct contour. Intermediate frames were hydro formed with the attach rings machined. The welding fixture shown in figure 47 for the honeycomb sandwiched inner liner was also used as the assembly jig for the aft segment; however, a separate assembly jig was required for the forward segment as shown in figure 48.

Thrust reverser. - The thrust reverser shown in figures 36 and 51 was configured with identical doors top and bottom, left and right hand side for complete interchangeability. The area and lip design was configured to produce essentially the same total retarding effect on the airplane during normal landing roll deployment as on the production DC-9.

The thrust reverser was designed for ground operation only with the capability of remaining in the forward thrust mode if a loss of hydraulic power occurs in flight. The thrust reverser uses two target type doors for reverser operation. The door actuating linkage consists of a four bar linkage design with idler links, driver links, and overcenter links. The driver links connect to hydraulic actuators thru over center links which preload the driver links in the stowed position. See figures 52 and 53. Hydraulic pressure maintains the actuators in the stowed position at all times. A loss of hydraulic pressure will not affect the over center condition. In case of a failure which would apply hydraulic pressure to the deploy side of the actuator, latches at the front end of each door prevent deployment.

The doors were oriented 15° from vertical so that when deployed the exhaust gases would be directed upward and inboard and downward and outboard. This feature has reduced foreign object damage due to reingestion on the DC-9.

The thrust reverser doors shown in figure 54 were of skin and stiffener construction. The principal structural elements were two hinge frames, two intermediate frames, an aft closure, a forward closure with turning lip and the inner and outer skins. With the exception of the outer skin which was 2219 aluminum, essentially all of the sheet metal structure is Inconel 718. The hinge fittings and the latch bracket are 17-4 PH steel. Externally applied 6061 aluminum plates at two locations along the trailing edge serve as bumpers when the thrust reverser doors are deployed. The trailing edge of each bumper was protected with a heat resistant alloy to protect it from exhaust gas impingement and to enhance the wear resistance when the bumpers from the door pairs are in contact.

Streamline fairings (stangs), fabricated in three pieces, were provided to cover the thrust reverser actuators and support structure. See figure 55.

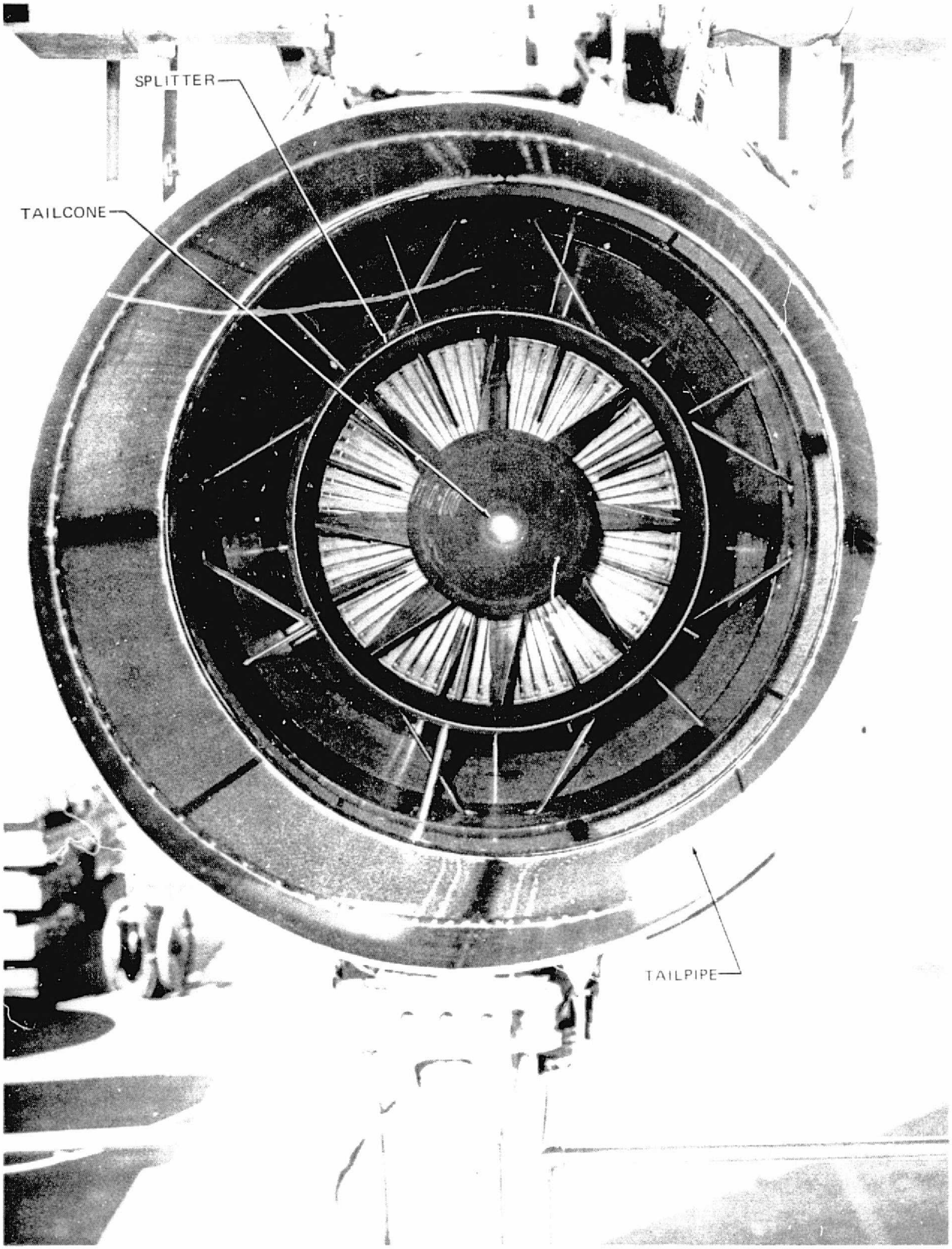

FIGURE 50. REAR VIEW – ENGINE AND EXHAUST SYSTEM

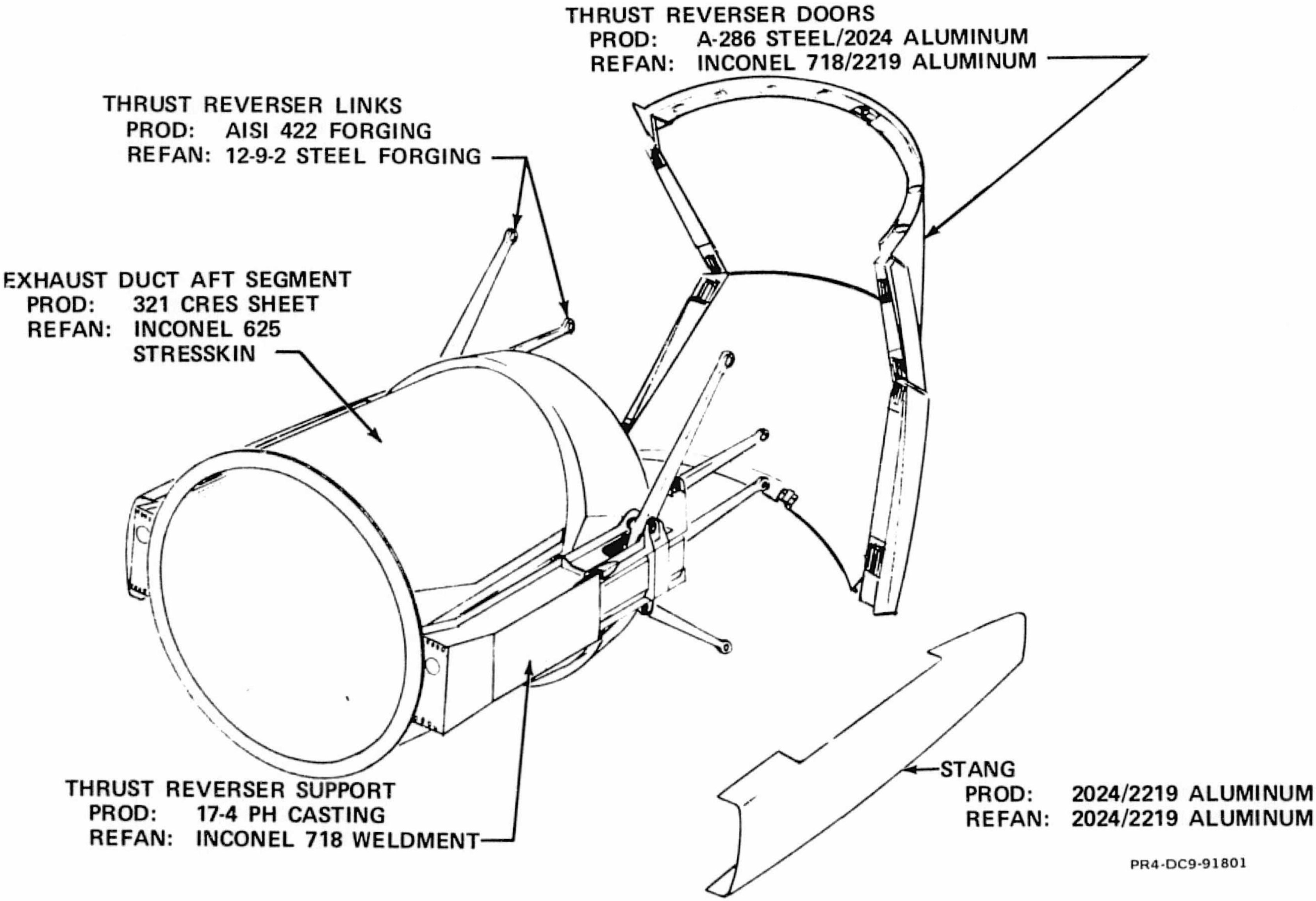

FIGURE 51. THRUST REVERSER MATERIAL SELECTION

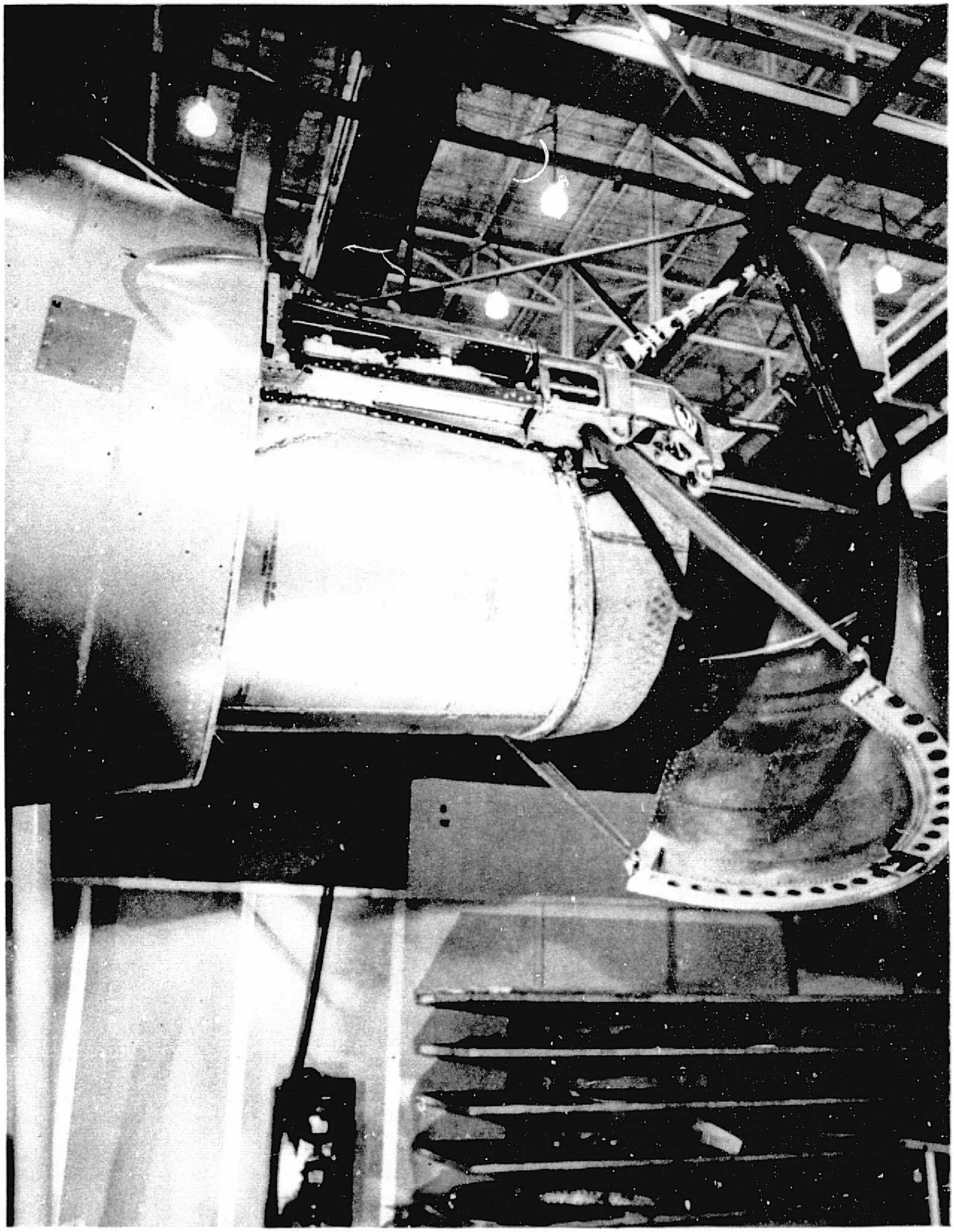

FIGURE 52. THRUST REVERSER, LINKAGE, ACTUATOR AND SUPPORT STRUCTURE

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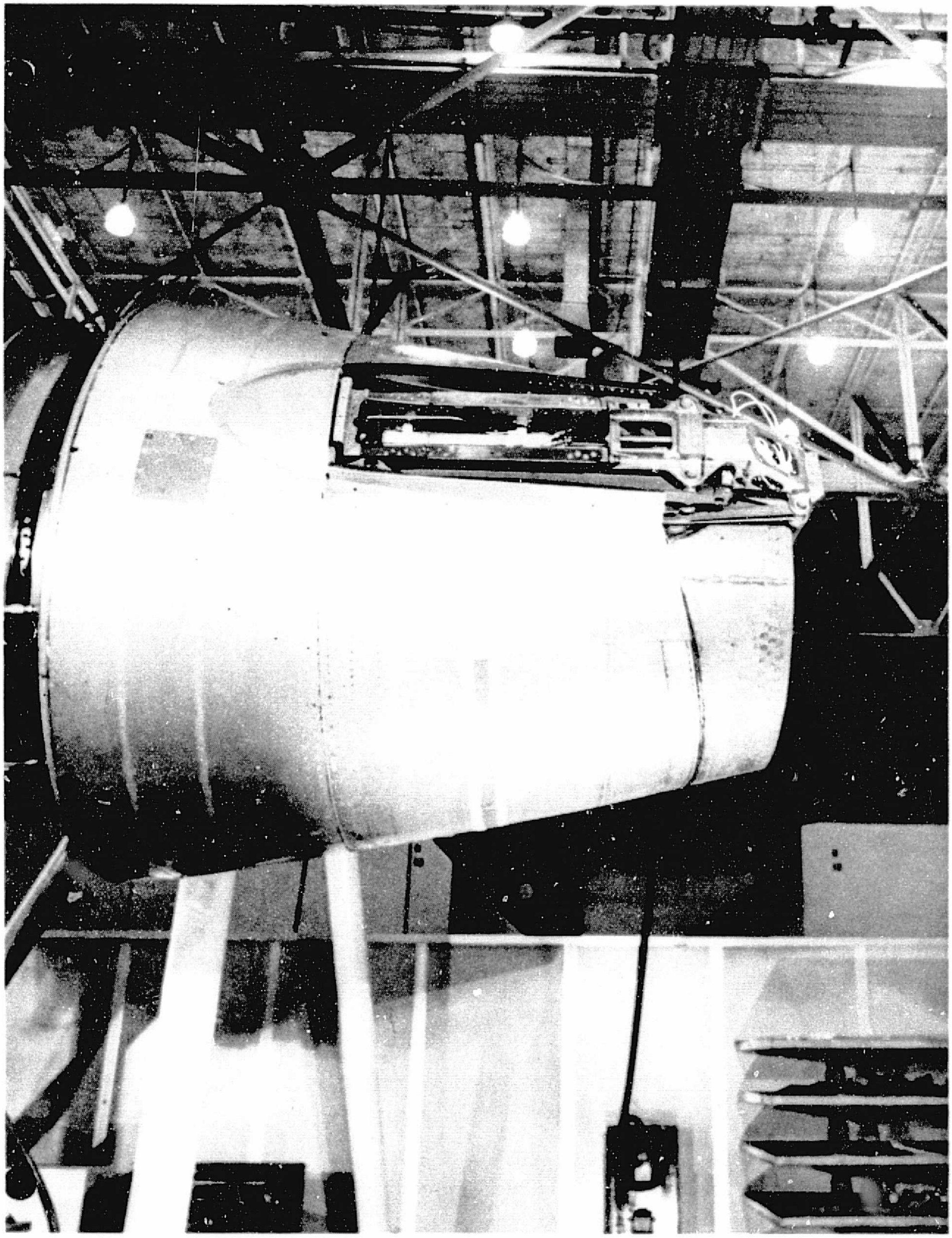

FIGURE 53. THRUST REVERSER SUPPORT STRUCTURE DOOR CLOSED

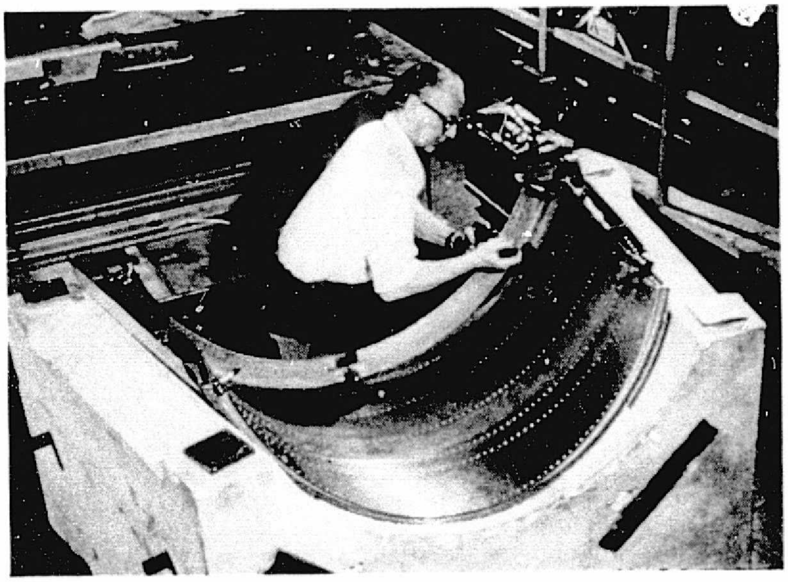

FIGURE 54. THRUST REVERSER DOOR IN TOOL

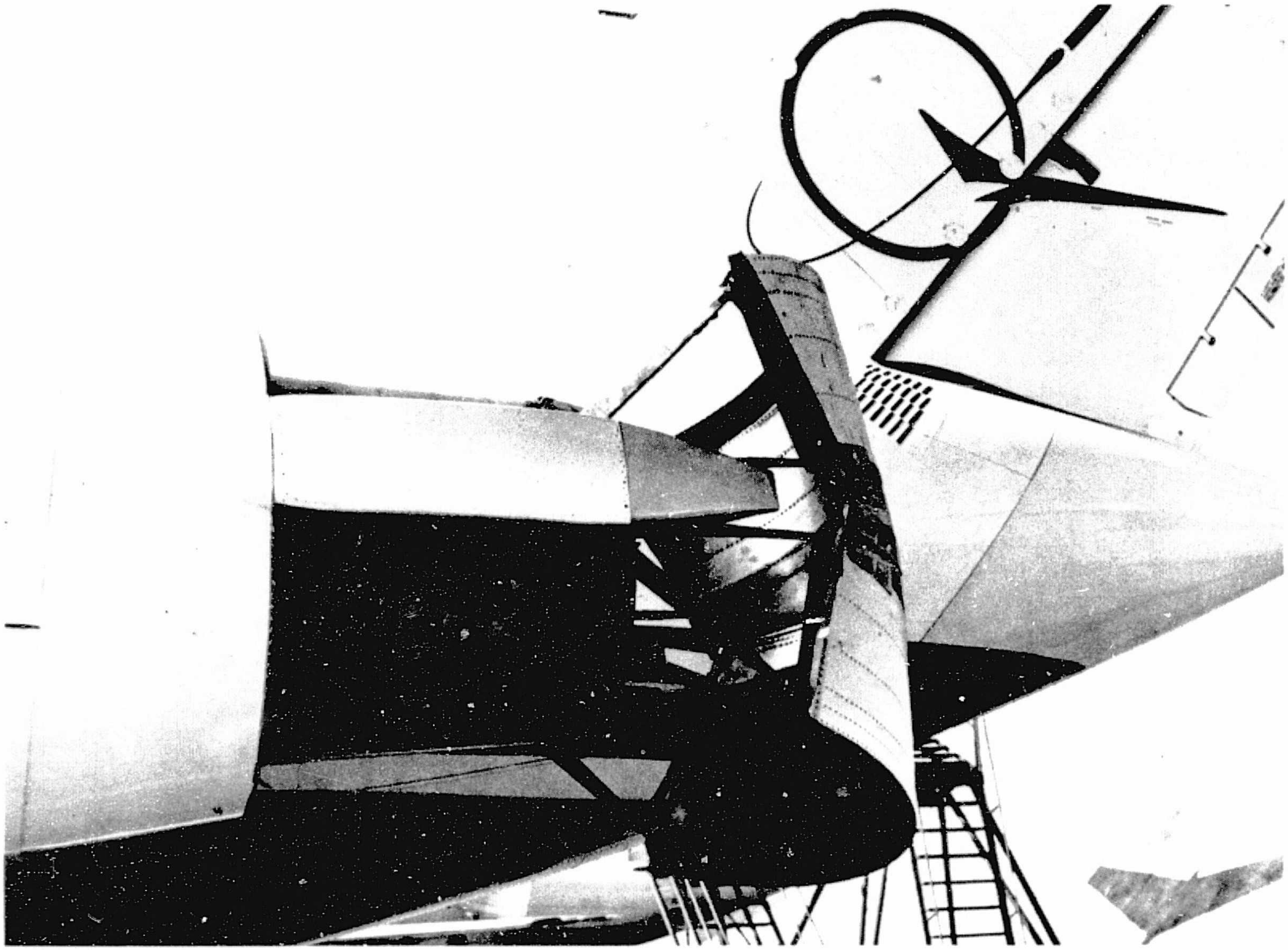

FIGURE 55. LEFT ENGINE THRUST REVERSER DEPLOYED POSITION

Thrust Reverser Controls

Two thrust reverser levers, one for each engine, were hinged to the top of the throttles. Each thrust reverser lever was connected to the throttle drum through a bellcrank, one end of the bellcrank acting as the cam follower, and the other end attached to the throttle pushrod. The bellcrank was controlled and operated by the thrust reverser lever when the throttles were in the idle position. Whenever the throttles are in the forward thrust range above idle, it is impossible to actuate the thrust reverser levers due to the bellcrank cam follower position on the throttle interlock cam.

Each thrust reverser lever had a total travel of 117 degrees. Movement of the levers upward through the first half of travel actuates the thrust reverser control valve and a feel detent in the fuel control unit is engaged. Movement of the levers above the detent produced the desired reverse thrust rating.

A mechanical latch for each door prevents the doors from deployment in case of an uncommanded hydraulic signal. During normal reverse operation, a cam driven by the engine cross-shaft, actuates the latch cables to release the latches thus allowing the doors to deploy. A latch position indicator for each door will protrude thru a slot near the aft end of the exhaust duct forward segment if the doors are stowed but not latched. The Refan reverser control system was identical to the DC-9 except latching was provided for both upper and lower doors. See figure 56.

Crew indication of thrust reverser operation was by two reverser position lights located on the cockpit glare shield. Aft movement of the thrust reverser lever unlatches the reverser at which time the amber engine reverse unlock light comes on. Deployment of the reverser mechanically moves the reverse interlock stop to permit the thrust application in the reverse range. The interlock/feedback cam moves as the reversers start to deploy. When the reversers are fully deployed the cam actuates a switch to turn on the blue engine reverse thrust light.

Hydraulic power for each reverser was derived from the respective main hydraulic system. Two accumulators and an isolation valve are incorporated for each reverser, figure 57, to maintain stow pressure and isolate the reverser hydraulic system from the main hydraulic system in flight. A caution light in the cockpit indicates if accumulator pressure was low.

The larger thrust reverser doors for the Refan engine and nacelle required that the following changes be made to the hydraulic system.

1. Redesign the hydraulic actuators to meet the load and stroke requirements. The cyclinder diameter was increased to provide larger piston and rod diameters (larger working areas); the snubber stroke was increased to prevent pressure spikes from occuring inside the cylinder. See figure 58 and 59 for size comparison and figure 60 for load vs stroke comparison.

2. Redesign the control valve to meet increased flow requirements. This was done by incorporating larger porting, and piston and sleeve metering

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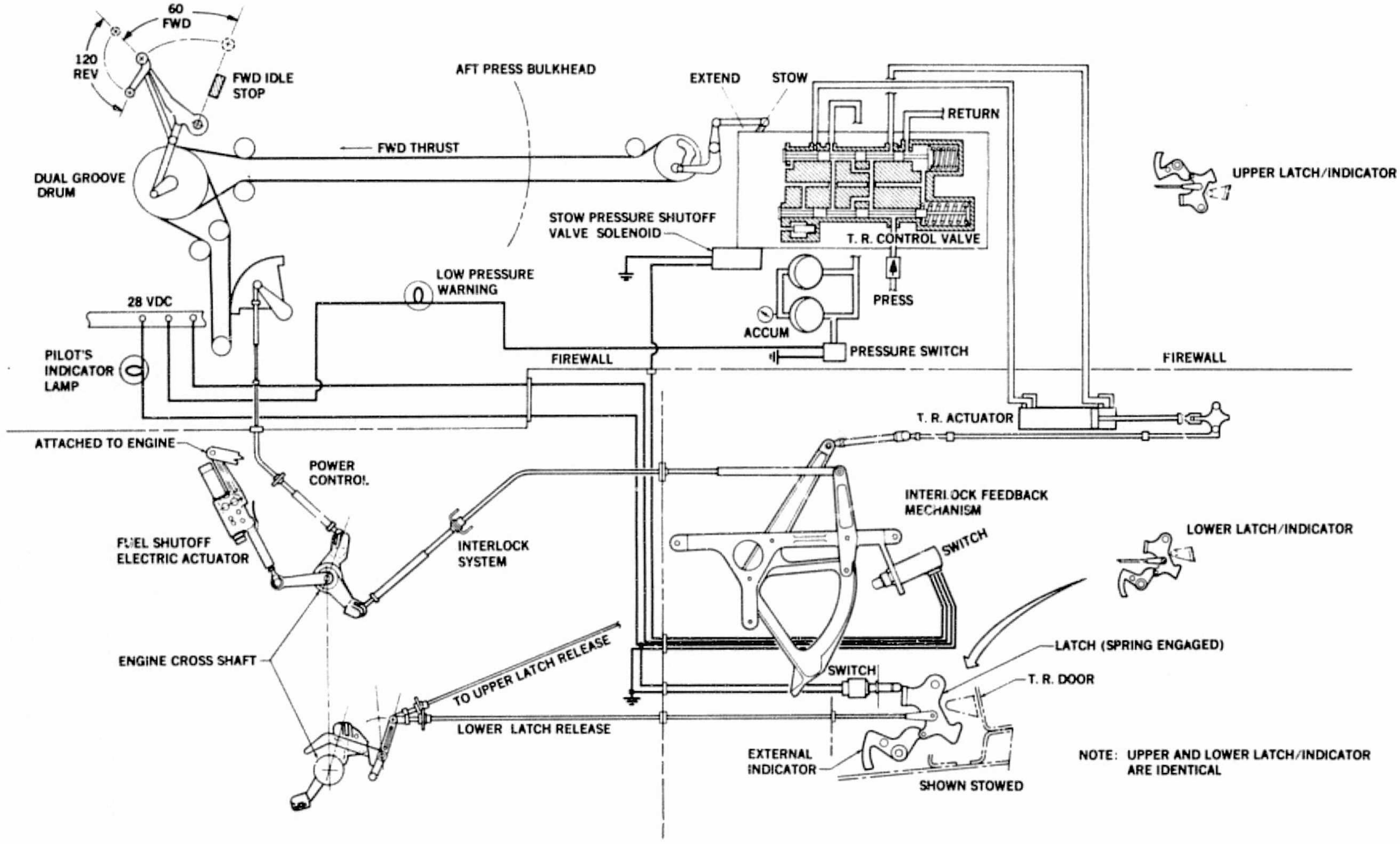

FIGURE 56. ENGINE AND THRUST REVERSER CONTROLS

PR3-DC9-91500

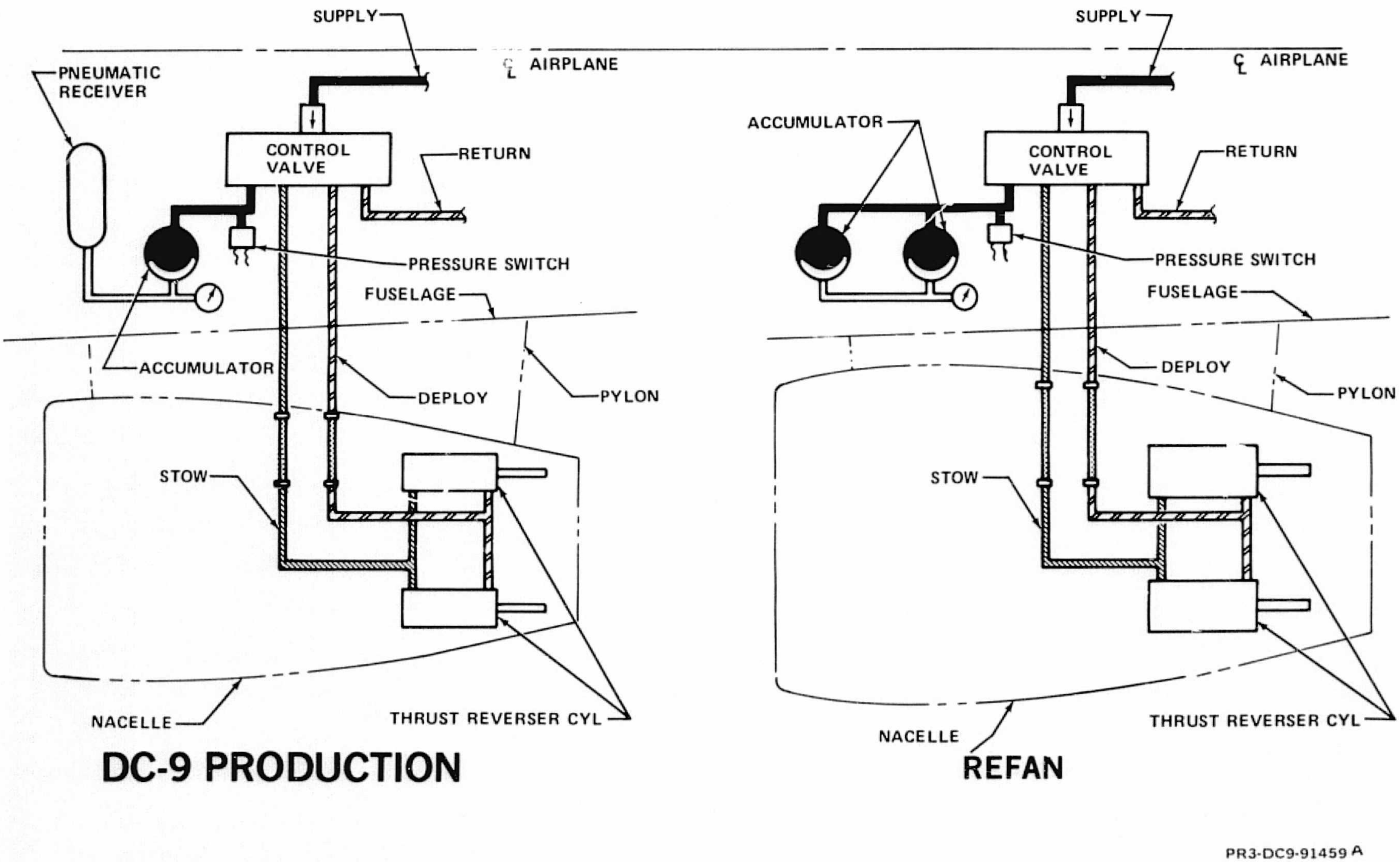

FIGURE 57. THRUST REVERSER HYDRAULIC SYSTEM SCHEMATIC

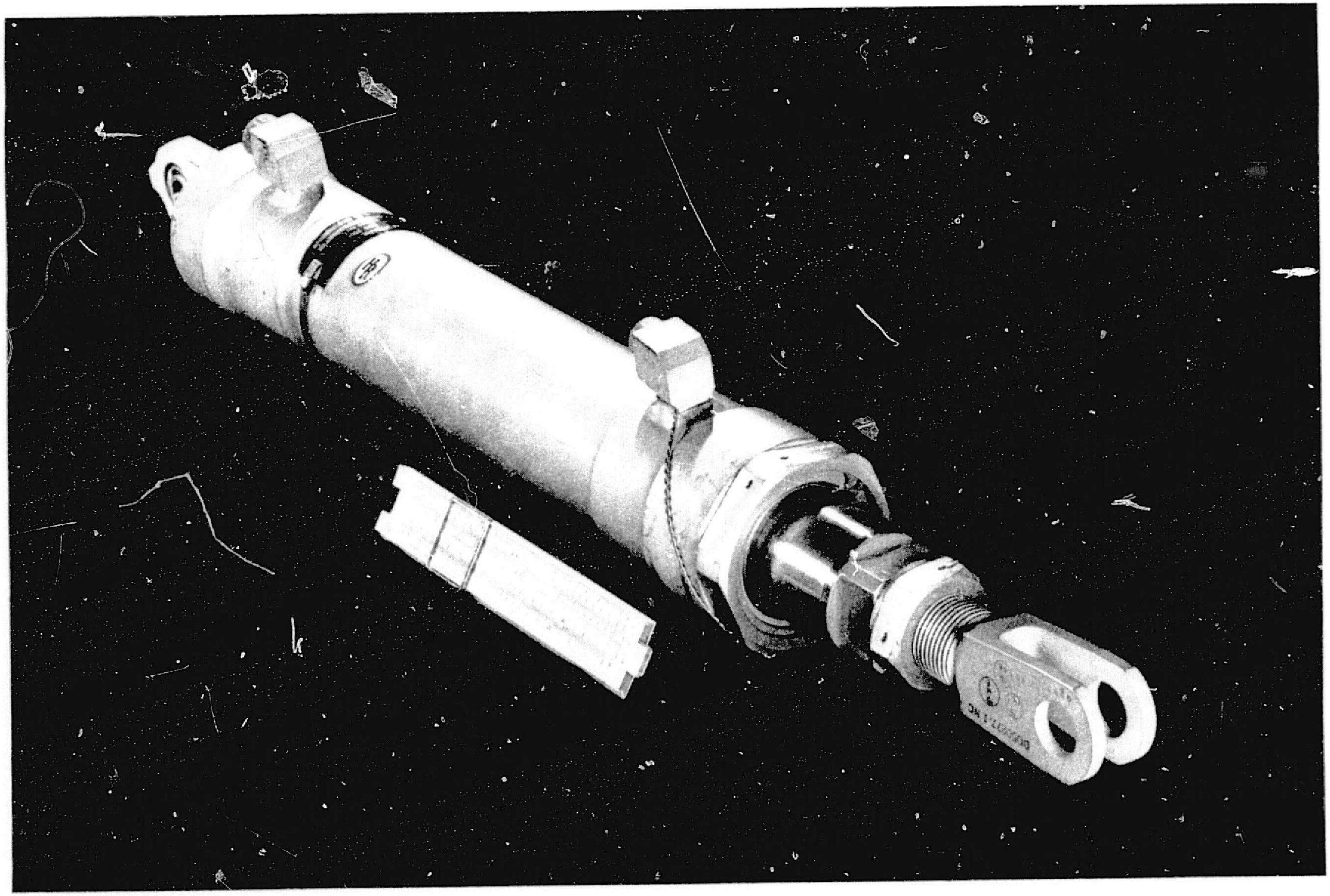

FIGURE 58. THRUST REVERSER ACTUATOR

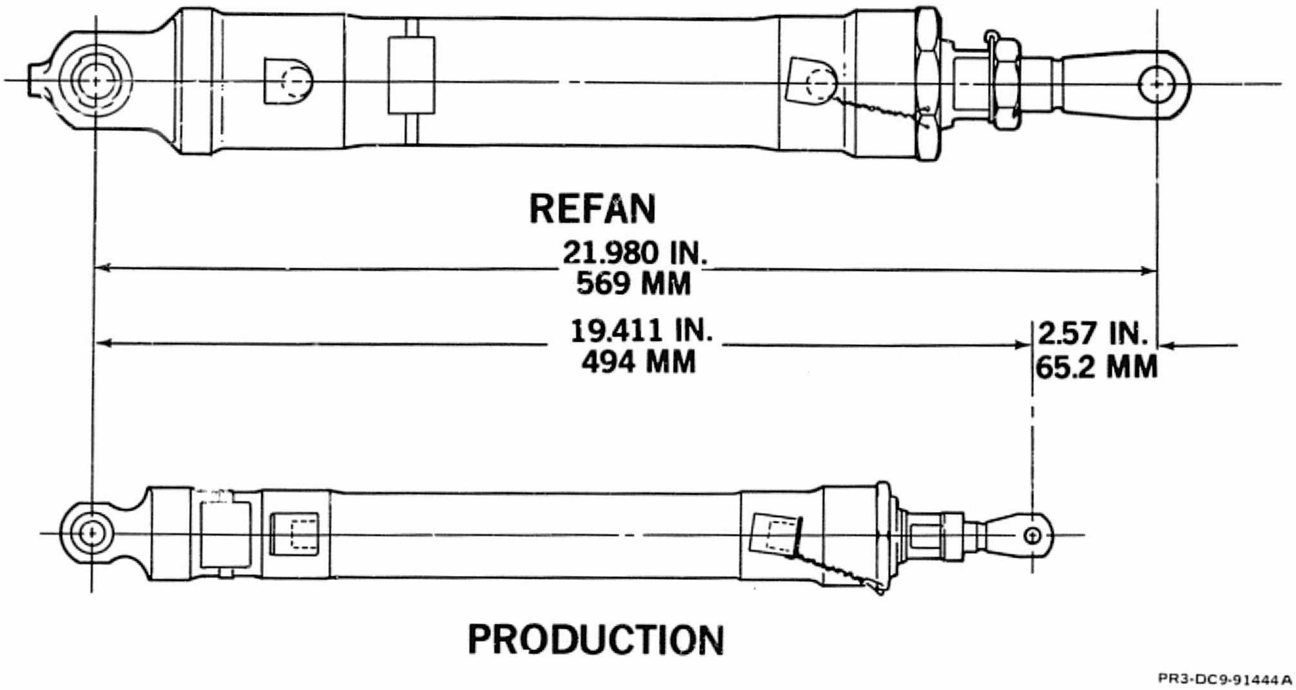

FIGURE 59. THRUST REVERSER ACTUATOR CONFIGURATION

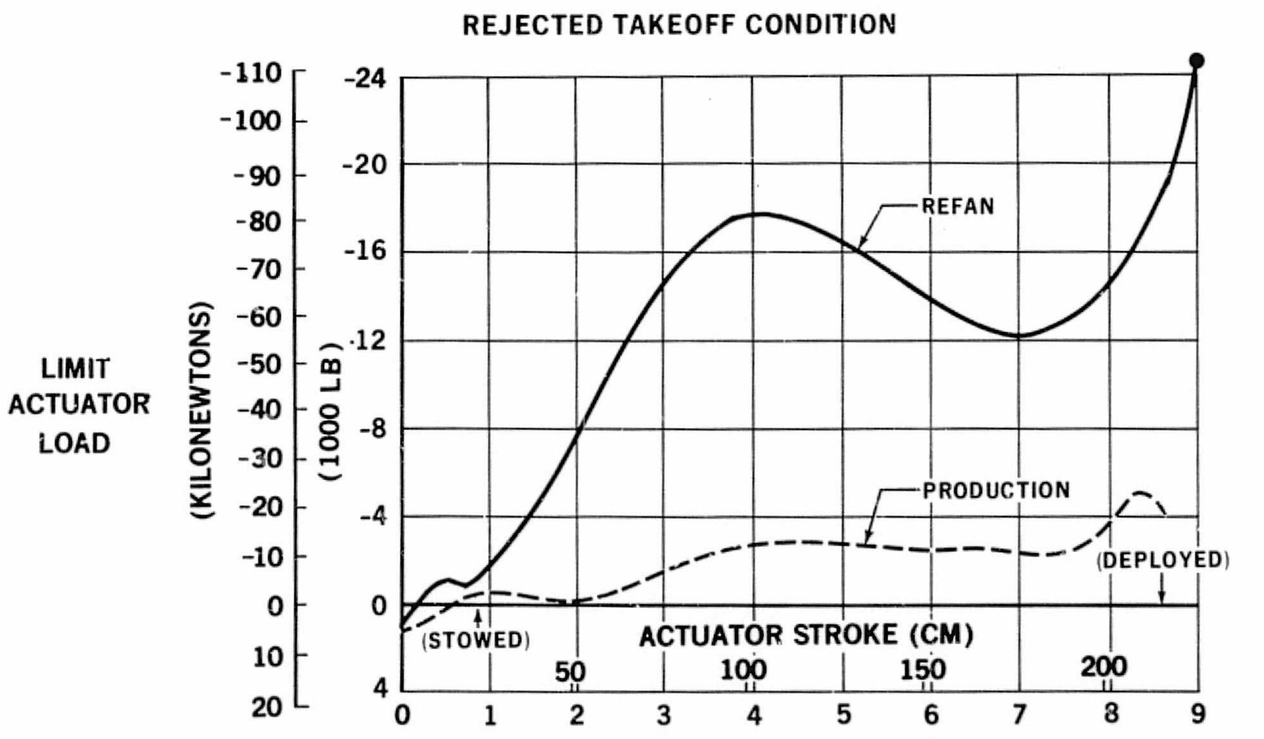

FIGURE 60. DC-9 THRUST REVERSER ACTUATOR LOAD VERSUS STROKE

orifice diameters. The valve mounting envelope, and electrical and mechanical control interface was not changed. See figure 61.

3. Increase the accumulator capacity. A second production accummulator was added to both the left and right hydraulic systems. The pneumatic receiver was removed since accumulator volume is sufficient without this unit. See figure 57.

4. Increase the sizes of the lines and fittings in the fuselage, pylon, and nacelle to make them compatible with the system flow requirements.

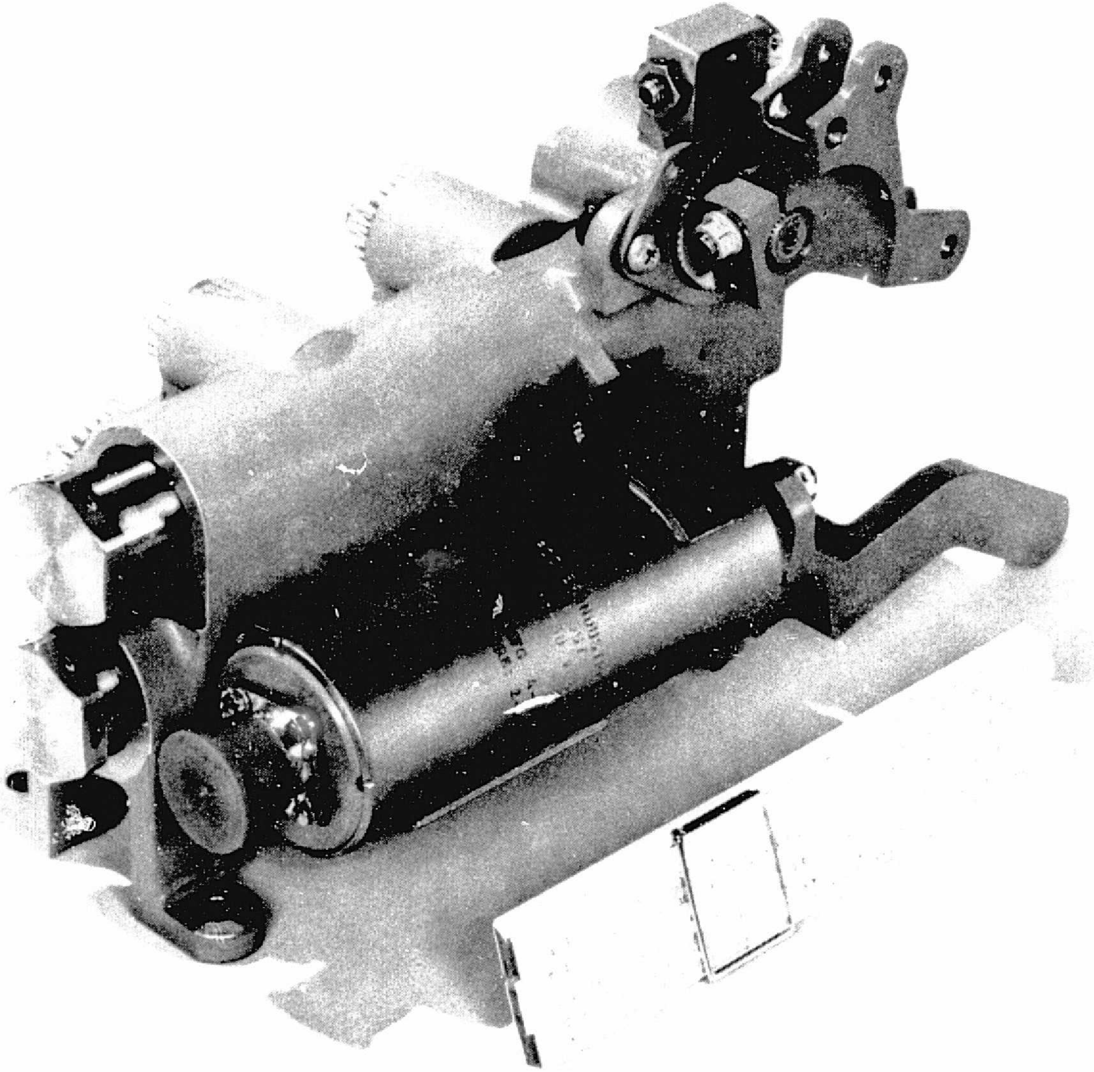

FIGURE 61. THRUST REVERSER CONTROL VALVE

Engine and Nacelle Subsystem Development

Since the Refan Program concept was to retrofit the existing fleet of DC-9 aircraft, the engine and airframe subsystems were examined for minimum change and impact on retrofit while achieving a desired level of performance and noise. It was determined that the existing DC-9 power plant subsystem arrangement could be retained with little or no modification to the components; however, redevelopment of most of the associated subsystem ducting, piping, and wiring was required.

Interchangeability. - The engine installation was designed with a major emphasis on maximizing the number of components which were common to the left and right demountable power plants. All elements of the Refan quick engine change package (QEC) are common to the left and right hand sides except the starter ducts and the 8th and 13th stage pneumatic ducting downstream of the cross-over manifolds. The DC-9 common parts exclude the nose cowls and the starter ducts. Commonality is desirable to reduce the cost of spares provisioning and QEC change time. See figure 62.

Commonality. - Table 1 indicates the extent to which the DC-9 subsystem major components were either retained, modified, redeveloped or replaced.

Engine mockup. - The JT8D-109 Class III mockup engine, supplied by NASA, was an exact representation of the external details of a released engine design. All parts had been manufactured to released engineering drawings and have been inspected for conformance to the manufacturing tolerances specified on the drawing. Changed or supplemental parts were installed so that it was kept up-to-date during the development period.

The engine was mounted on an existing fixture first used for the DC-9 mockup including the forward and aft engine mounting arrangement. Horizontal spars were added to accommodate the different relative locations of the Refan engine mounts. See figure 63.

Before development of piping and wire routing and support was started, the engine manufacturer's flange brackets and left engine production parts, drawn from stock, were installed. As seen on figures 63 and 64, components such as the hydraulic pump, starter, starter shutoff valve, constant speed drive (CSD), CSD oil cooler, generator and cooling shrouds, 8th and 13th stage pneumatic cross-over ducts, fuel flow transmitter, starter duct and electrical junction box supports, fire detector support brackets, fuel cross over tube, fuel eductor and bracket, oil system transmitters, and some DC-9 over board drain pipes attaching to the gearbox were installed. Development of piping, ducting, and wiring, including fit and clearance verification of subsystem parts are noted in the text.

The mockup engine was also used as an installation fixture to mount and actuate the left engine thrust reverser and tailpipe that was tested at Pratt and Whitney to demonstrate the compatibility of the JT8D-109 with the Douglas inlet and exhaust system. Figure 65 shows the thrust reverser

TABLE 1
REFAN COMMONALITY MATRIX

ITEM DESCRIPTION	CHANGES REQUIRED FOR JT8D-109 ENGINE INSTALLATION			
	RETAIN EXISTING ITEM(S)	MODIFY EXISTING ITEM(S)	REDEVELOP DUCTS, WIRING, ETC.	REPLACE
Electrical System				
Generator	X			
Generator Cooling Ducts	X			
J-Box and Support	X			
T/R Harness				X
Gen Pwr Harness		X		
Gen Cont Harness		X		
P/P Misc Harness		X		
Pylon F.D. Harness	X			
Constant Speed Drive	X			
CSD Hoses	X			
CSD Oil Cooler	X			
Hydraulic System			X	
Pump	X			
Hoses	X			
"Bridle" Supt Brkts	X			
Fuel System			X	
Eductor	X			
Crossover Pipe	X			
Controls System				
Throttle				X
Fuel Shutoff				X
Engine Indicating Systems		X		
Engine Pressure Ratio	X		X	
Engine Exhaust Gas Temp	X			
Engine Tachometer	X			
Fuel Flow and Fuel Used	X			
Power Supply, Regulated Frequency	X			
Fuel Inlet Pres Caution	X			
Fuel Filter Differential Pressure Caution	X			
Fuel Heater Control & Ind	X			
Low Engine Oil Pres Caution	X			
Engine Oil Strainer Caution	X			
Fuel Temperature	X			
Engine Oil Pressure	X			
Engine Oil Temp	X			
Engine Oil Quantity	X			
RAT Vs EPR Indicator		X		

TABLE 1
REFAN COMMONALITY MATRIX (CONT)

	CHANGES REQUIRED FOR JT8D-109 ENGINE INSTALLATION			
ITEM DESCRIPTION	RETAIN EXISTING ITEM(S)	MODIFY EXISTING ITEM(S)	REDEVELOP DUCTS, WIRING, ETC.	REPLACE
Engine, Turbofan				X
Nose Cowl				X
Inlet Bullet				X
Access Doors				X
Apron				X
Exhaust Ducts				X
Thrust Reverser				X
T/R Controls				X
Engine Bleed Air System				
8th Stage Manifold		X		
13th Stage Manifold		X		
8th Stage Check Valve		X		
Engine and Nose Cowl			X	
Ice Protection				
Engine Anti-Icing Valve	X			
Cowl Anti-Icing Valve	X			
Thermostatic Valve	X			
Nose Cowl Ejector				X
13th Stage Pipe		X		
Fire Projection System		X		
Engine Fire Detector	X			
Pylon Fire Detector		X		
Firex Container		X		
Discharge Lines & Fittings				X
Engine Oil System	X		X	
Oil Pres X-mitter	X			
Oil Temp X-mitter	X			
Low Oil Pres SW	X			
Filter Lo Pres Caution	X			
Cooling & Ventilation		X		
Engine and Nacelle Drains	X	X		
Engine Starting System			X	
Starter	X			
Starter S/O Valve	X			
Starter Pneu Ducts				X

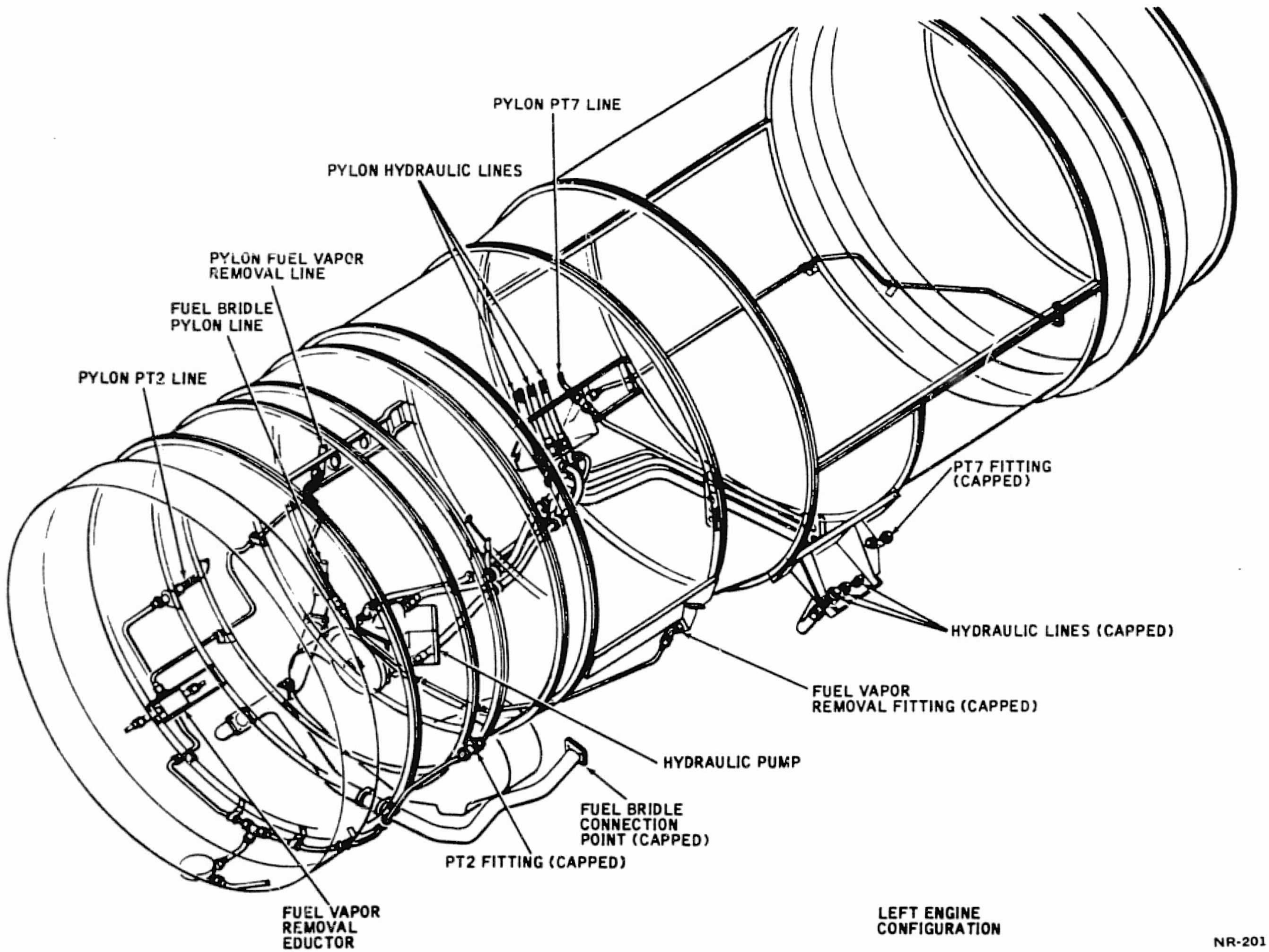

FIGURE 62. DEMOUNTABLE POWER PLANT (INTERCHANGEABILITY)

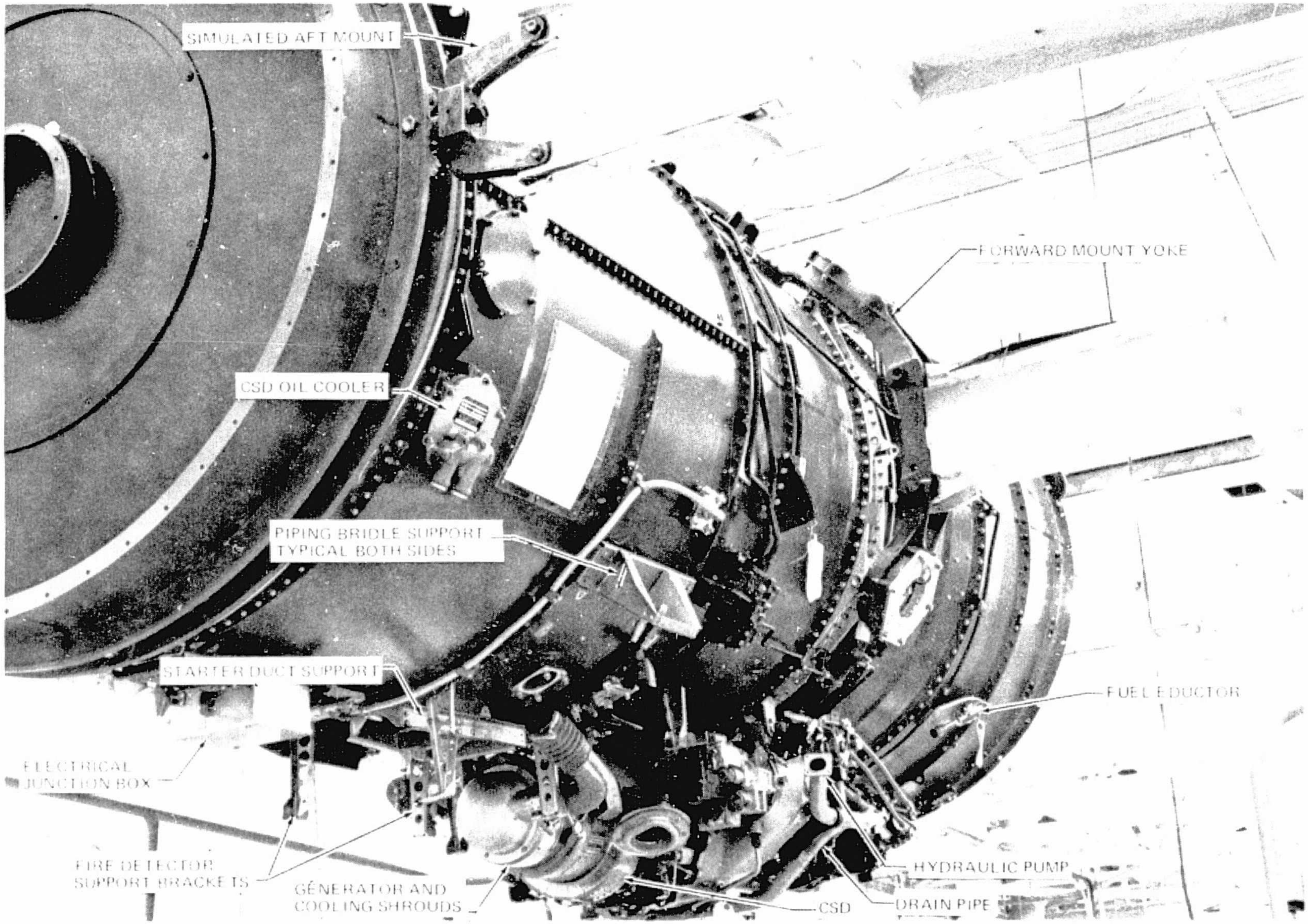

FIGURE 63. RIGHT SIDE – MOCKUP ENGINE AND MOUNTING FIXTURE

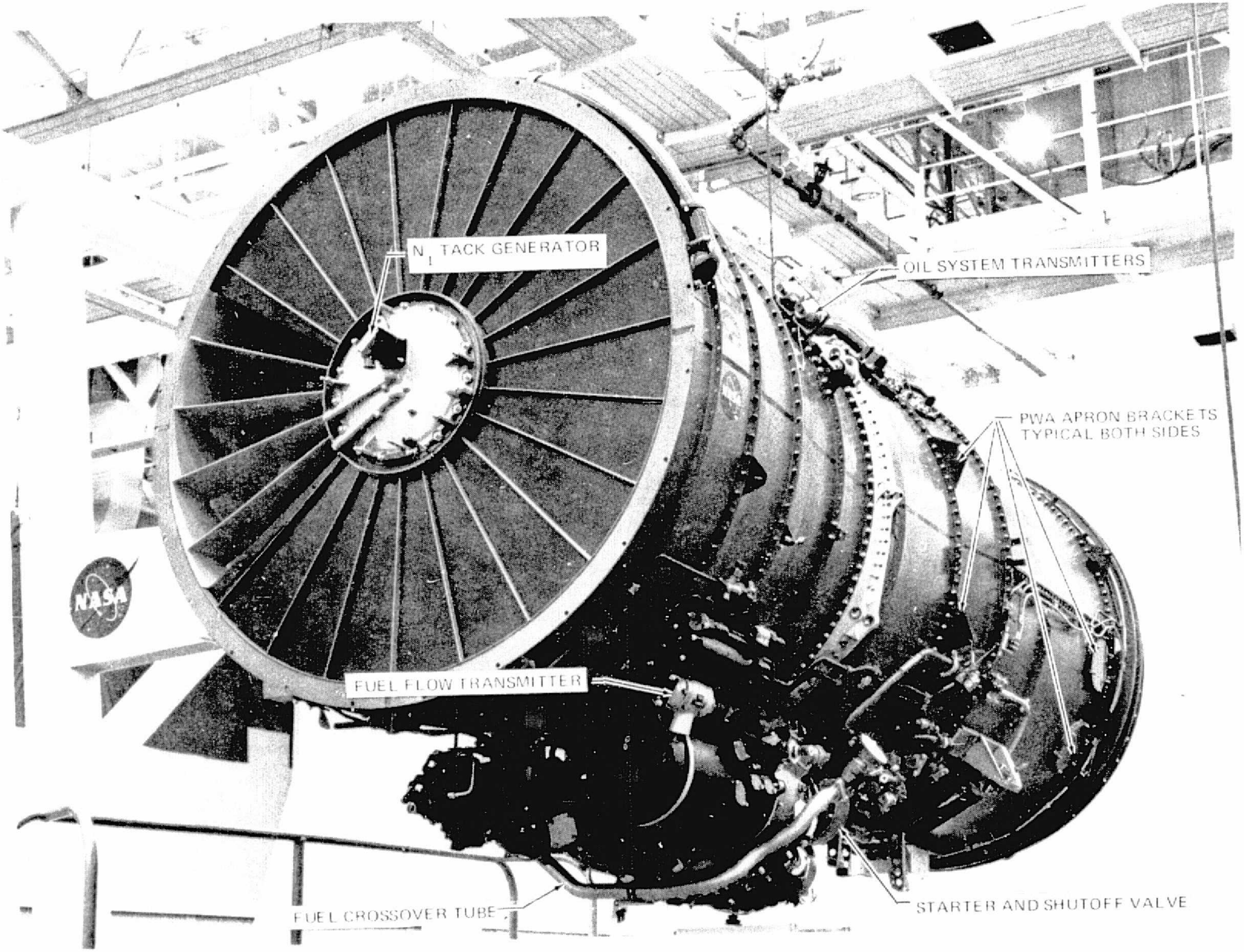

FIGURE 64. MOCKUP ENGINE – LEFT SIDE

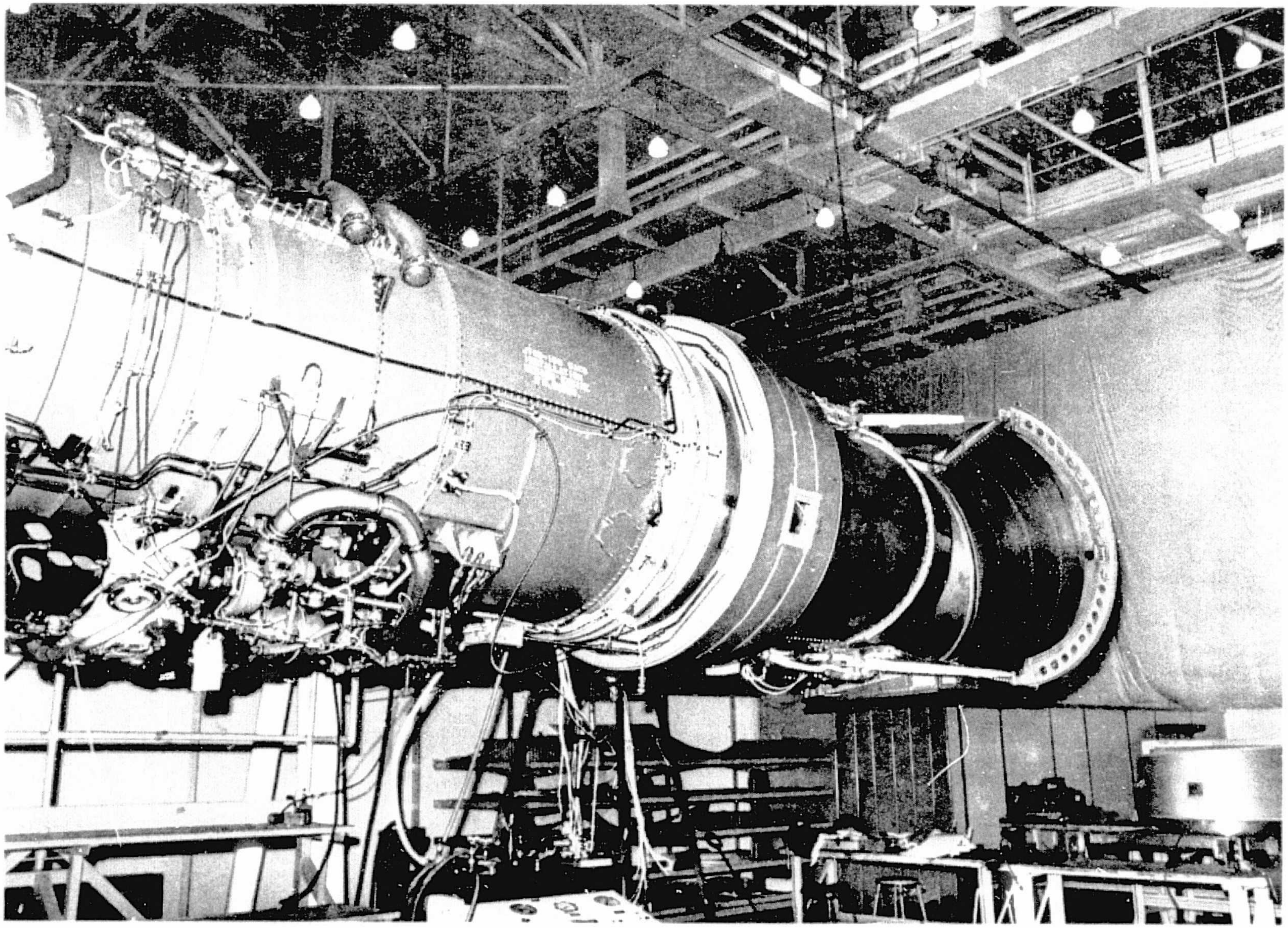

FIGURE 65. MOCKUP ENGINE – THRUST REVERSER HORIZONTALLY MOUNTED

installed in the horizontal position. Figure 66 shows the same unit mounted in the production position. Figures 67 and 68 show the Douglas inlet and tailpipe at Pratt and Whitney, Hartford installed on the test engine.

Upon completion of engine mockup work, the engine was installed on the airplane as shown in figure 69 in order to establish the length and routing of the interfacing services shown in figure 70. Figure 33 shows the interface hoses and wiring prior to installation of the engine. Proper fit and clearance of the throttle control and 8th and 13th stage pneumatic ducts were also verified.

Engine bleed air system. - The engine bleed air system for the JT8D-109 engine was schematically identical to the existing DC-9-32 system. Changes were limited to details of component relocation and modifications of duct routing dictated by the increase in engine physical size. Figure 71 shows the system schematically while figure 72 presents the general arrangement of the existing DC-9-32 installation.

The engine bleed air system includes two identical pneumatic subsystems, one for each engine. Although each subsystem was complete and capable of independent operation, they were interconnected to provide a common pneumatic source for the applicable airframe systems. Bleed air may be extracted from either the 8th or 13th engine compressor stages or from both. The 8th stage air from two ports on each engine was manifolded together and after passing through a check valve, as shown in figure 73, enters the crossfeed pneumatic manifold which interconnects the two engine subsystems and from which the air conditioning, airframe ice protection and engine start systems receive air. Pneumatic air can also be supplied to the crossfeed manifold from the aircraft APU through a check valve, or from a ground pneumatic source. Thirteenth stage air was extracted from two bleed ports on each engine and was manifolded together prior to entering the crossfeed pneumatic manifold through the augmentation valve.

The augmentation valve was located within the aircraft fuselage as close as possible to the bleed source in order to minimize the length of 13th stage bleed ducting. This valve has two operating modes: one used for air conditioning and the other for airframe ice protection. When the air conditioning systems only were in operation, the valve serves to augment the 8th stage supply if the pressure downstream of the augmentation valve falls below 18.5 psig. During airframe ice protection operation, the augmentaion valve controls the flow of the 13th stage bleed air to maintain a mixture of 8th and 13th stage air at a temperature of 450°F in the crossfeed manifold.

Two manually controlled, cable operated, crossfeed valves located in the crossfeed manifold were provided to isolate the two engine bleed air pneumatic subsystems. These valves are normally closed during air conditioning system operation. However, when ice protection operation is required, one or both are open. These valves are also open during engine starting, or in the event that both air conditioning systems are operated from one engine.

The engine mounted pneumatic and starter ducting was designed to fit either the left or right engine and attach to modified DC-9 8th and 13th stage manifolds. The 8th stage starter wye ducts were fabricated using

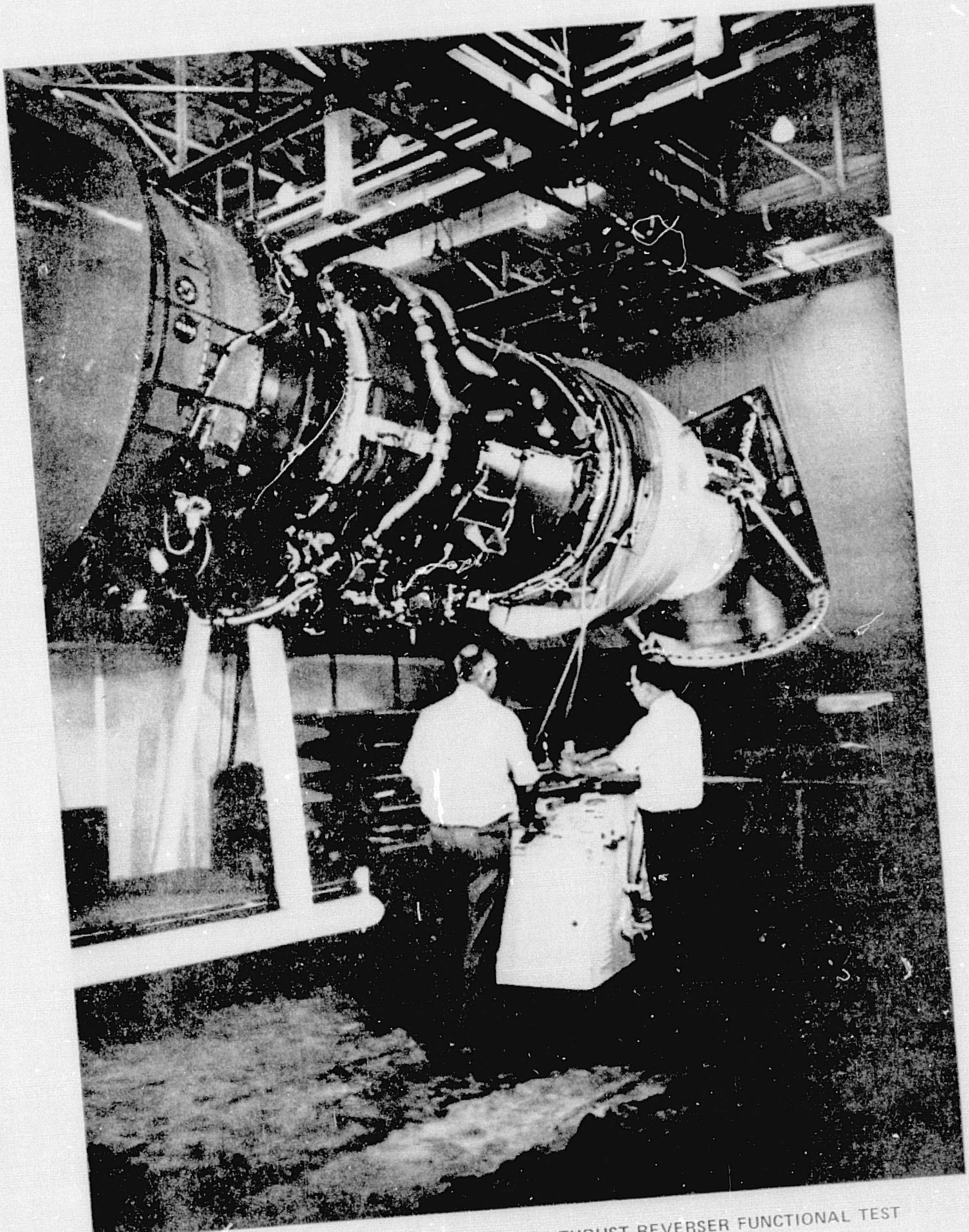

FIGURE 66. DC-9 REFAN JT8D-109 ENGINE THRUST REVERSER FUNCTIONAL TEST

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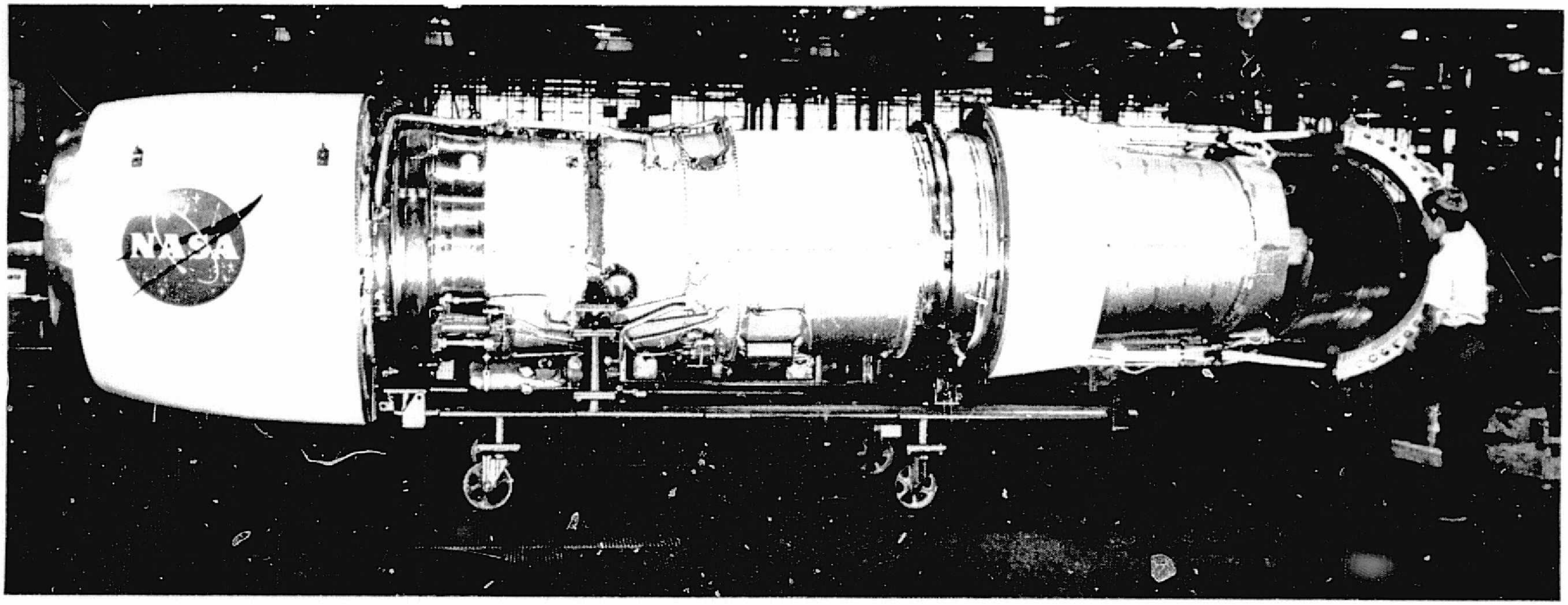

FIGURE 67. JT8D-109 ENGINE X-374-52 WITH FLIGHT INLET AND THRUST REVERSER IN DEPLOYED POSITION

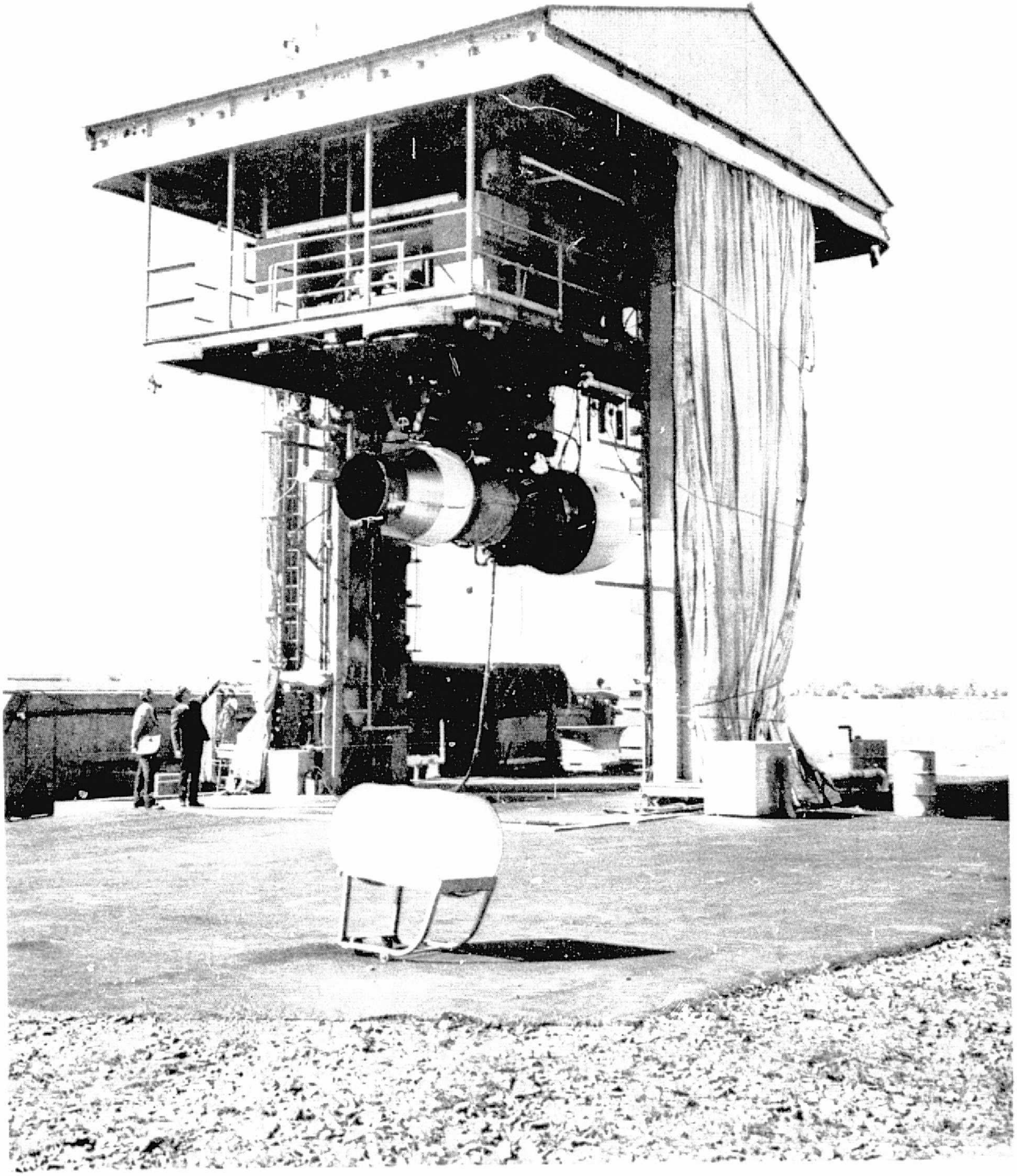

FIGURE 68. JT8D-109 ENGINE X-374-52 WITH FLIGHT INLET AND THRUST REVERSER INSTALLED; X-307 STAND, 10/74 AT P&WA/EAST HARTFORD, CONN.

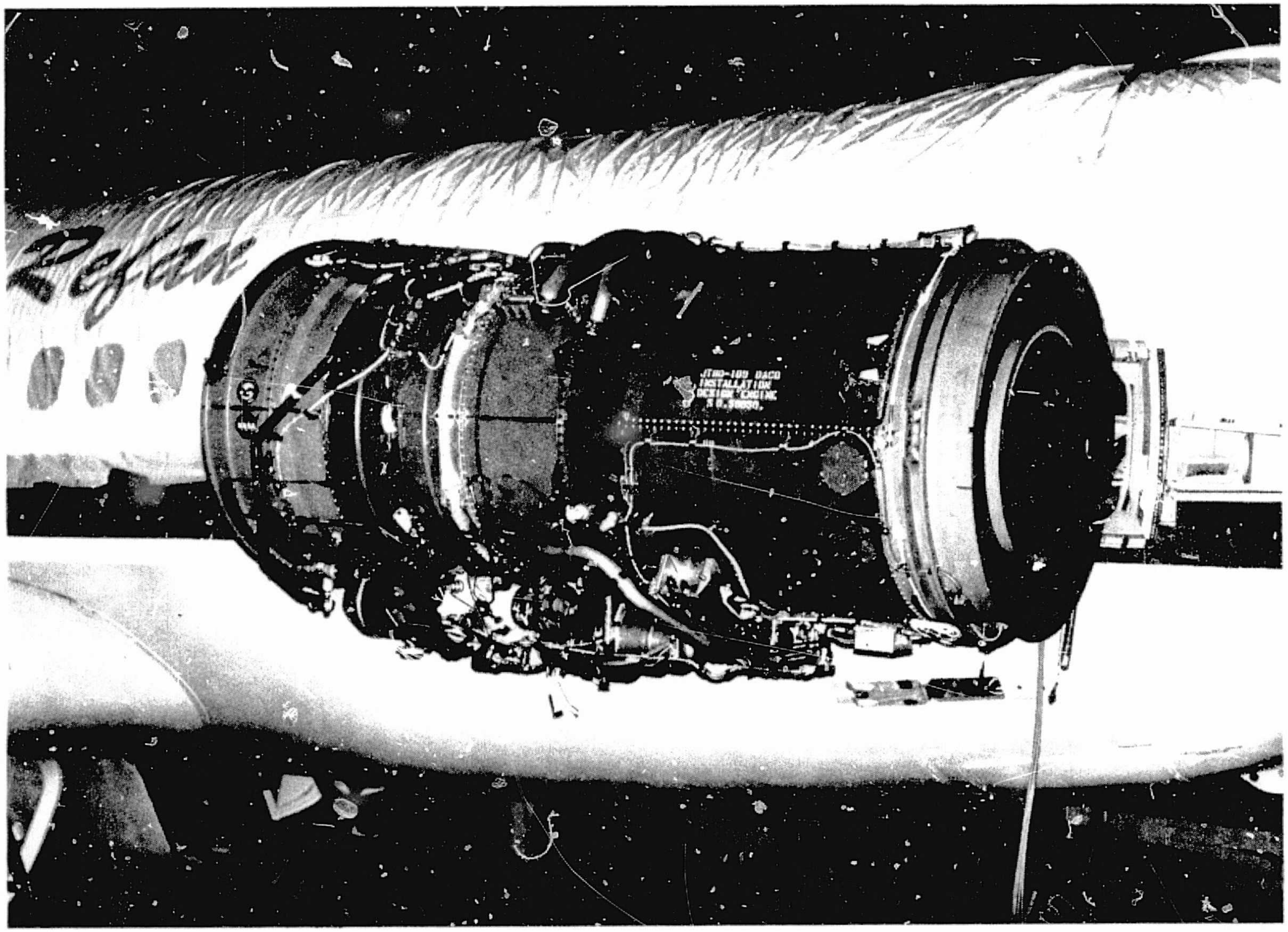

FIGURE 69. DC-9 REFAN CLASS III JT8D-109 MOCKUP ENGINE INSTALLED ON REFAN AIRPLANE LEFT PYLON

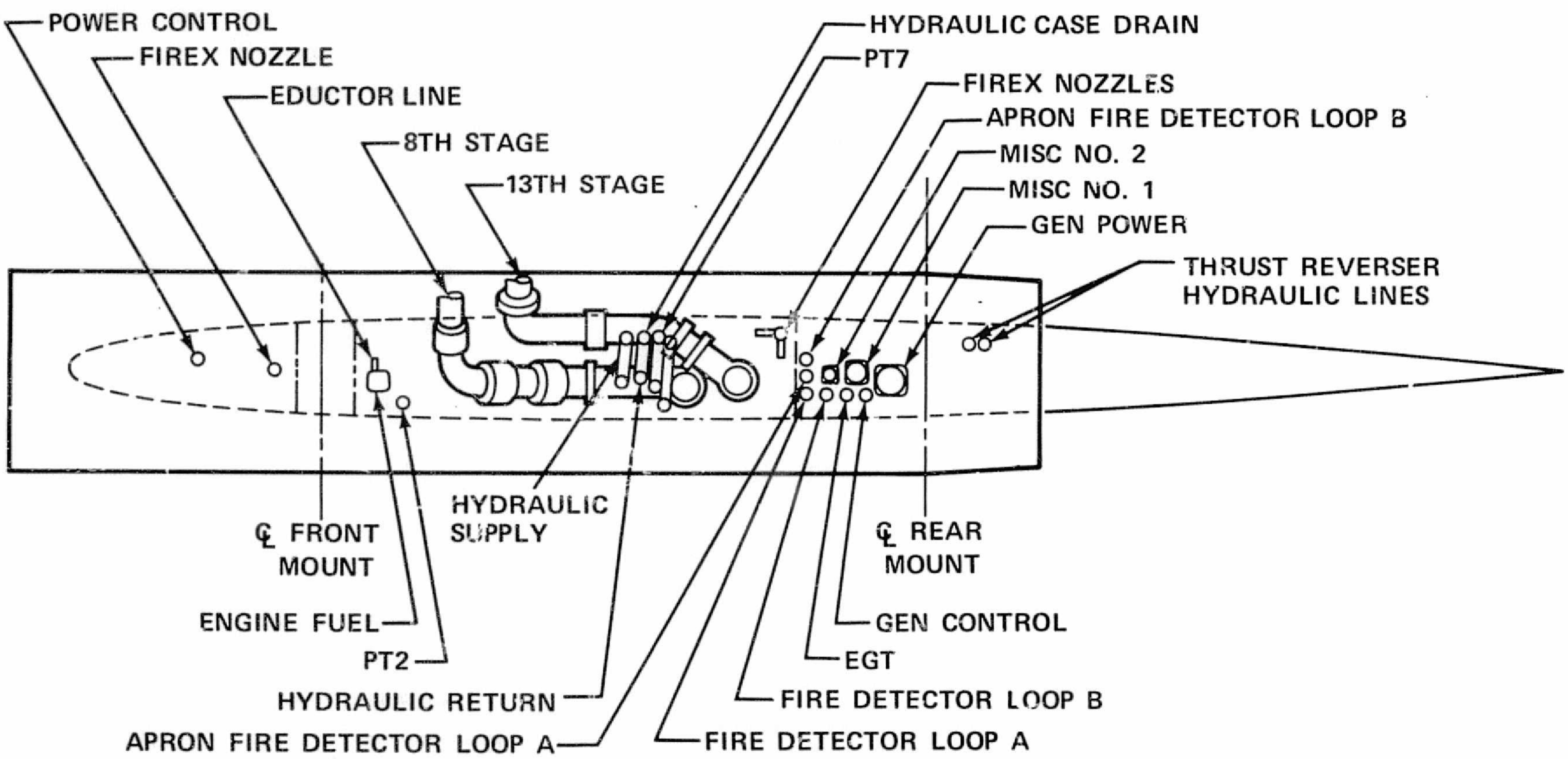

FIGURE 70. PYLON COMPONENTS INSTALLATION

PR3-DC9-91485

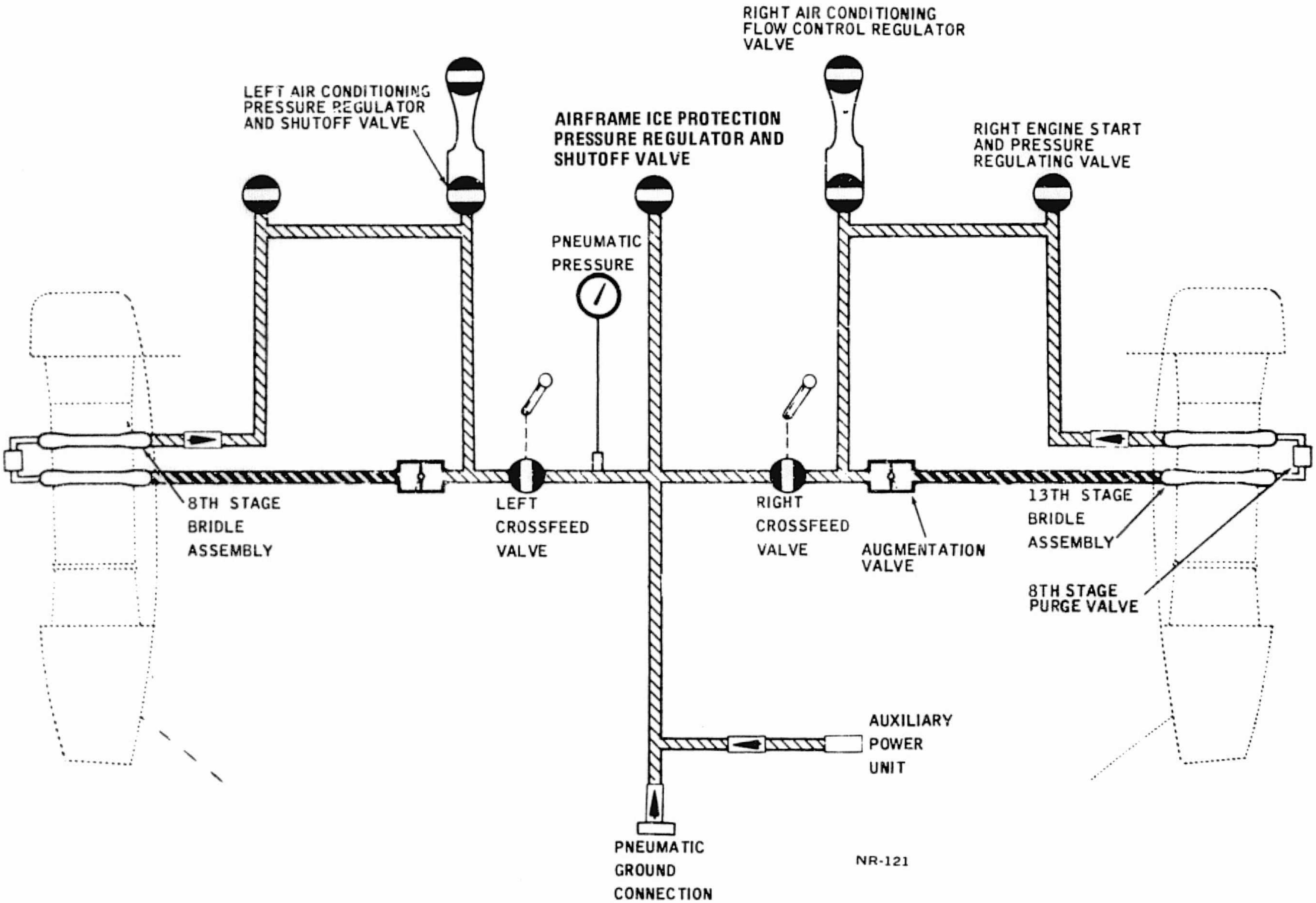

FIGURE 71. DC-9-32 AND REFAN BLEED AIR SYSTEM

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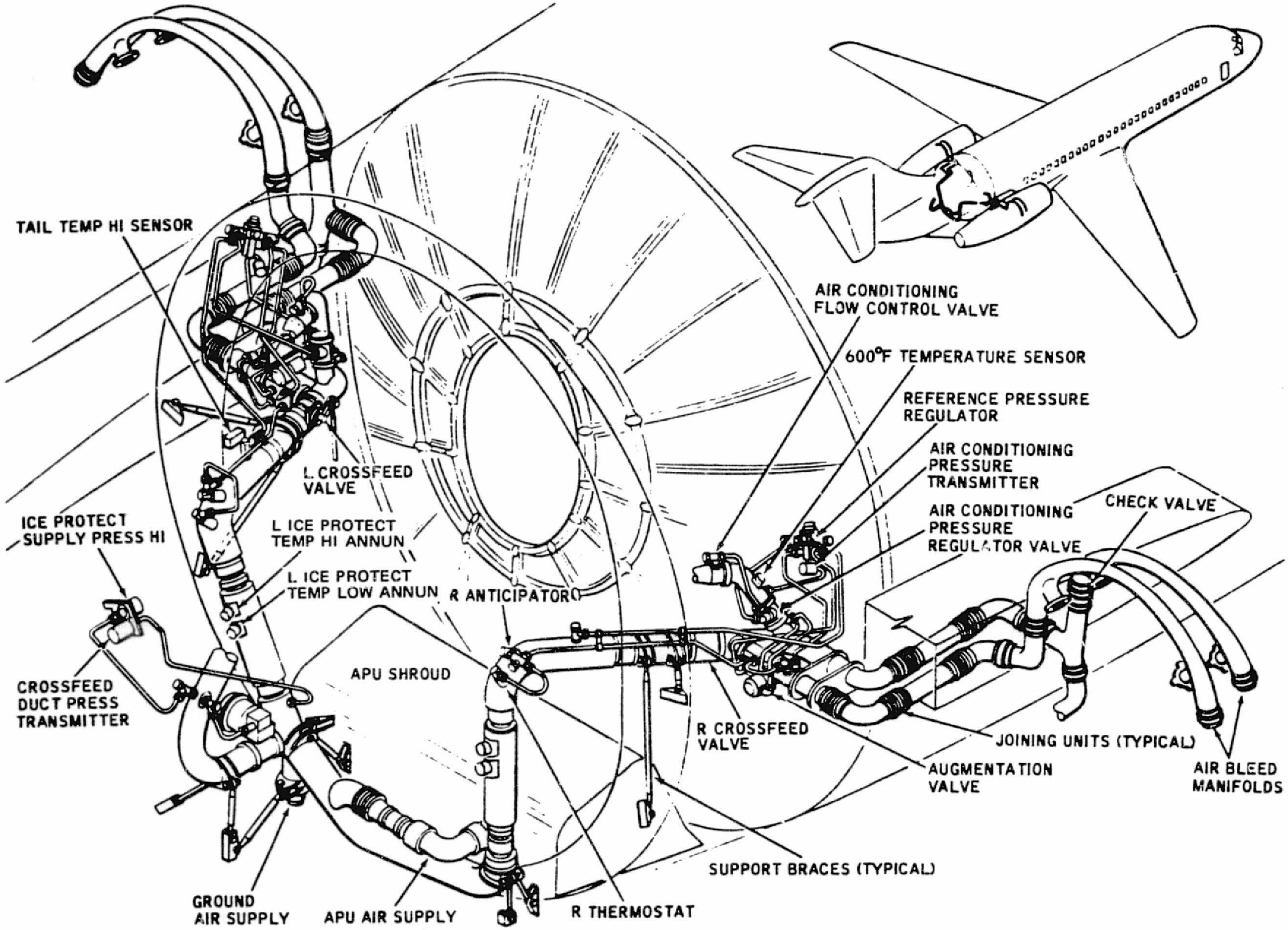

FIGURE 72. BLEED AIR SYSTEM GENERAL LAYOUT

NR-196

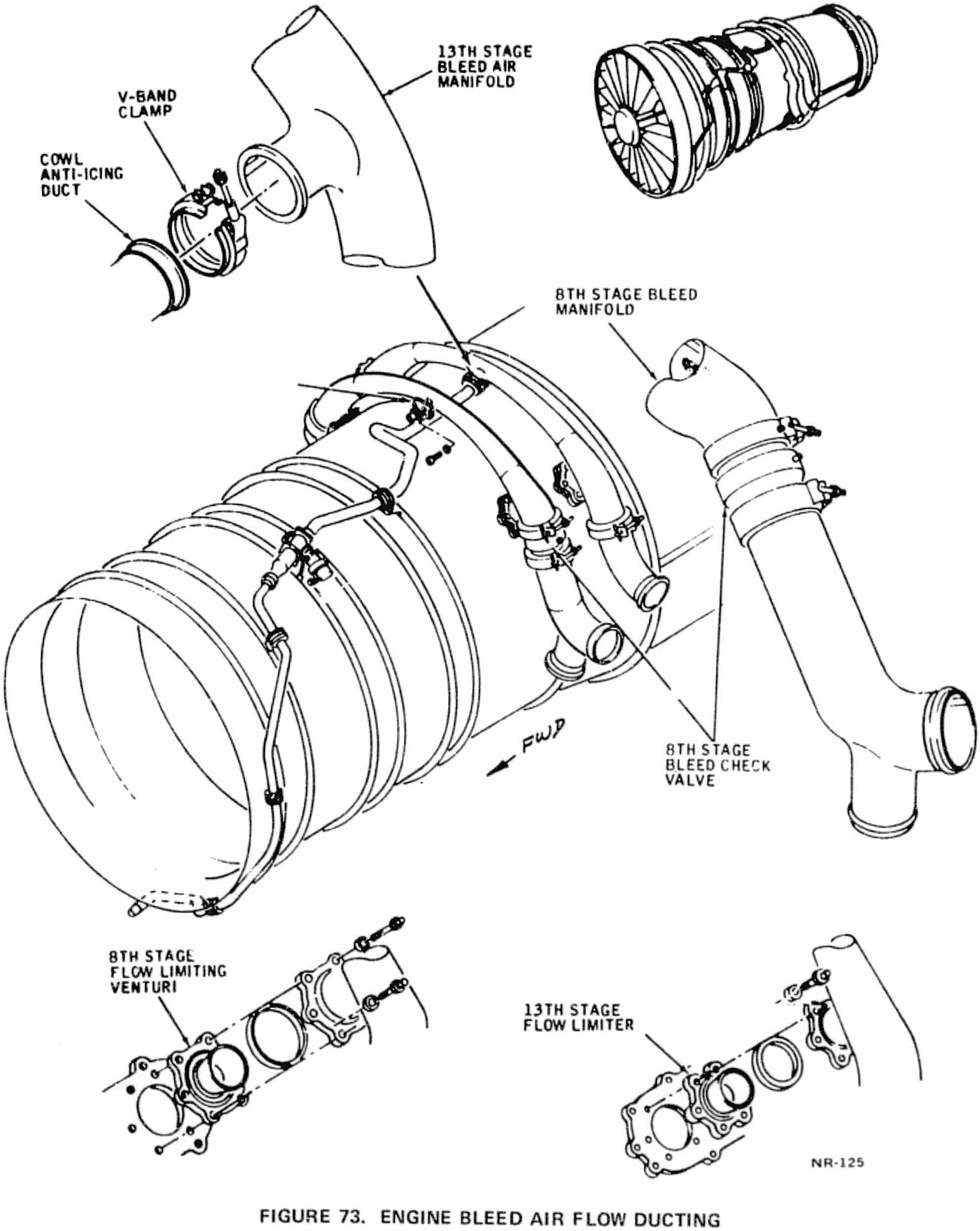

FIGURE 73. ENGINE BLEED AIR FLOW DUCTING

portions of DC-9 production ducts and end fittings. All other ducts were designed and fabricated for the Refan installation. Development of each system consisted of installation of the ducts and supporting hardware for detail fit and clearance checks. The left engine system is shown in figure 74; the right engine system is shown in figure 75; the 8th and 13th stage manifolds are shown in figure 76.

The 8th stage purge system, shown in figure 76 consists of a valve and interconnecting pipes between the 8th and 13th stage manifolds, was identical to the DC-9 installation. The valve opened when the engine was in reverse and air conditioning packs were turned off. By opening, it takes relatively clean 13th stage air to pressurize the 8th stage manifold with this air thus preventing entry of dust thru the 8th stage anulus (OD bleed) into the manifold. Development of this system consisted of mounting the value on its engine flange bracket and routing of the two sensing pipes.

Ice Protection. - The engine and nacelle inlet anti-icing system was schematically similar to the existing design, shown in figure 77. The only differences were those resulting from the increased engine size; the provision of acoustical treatment on the nacelle inlet duct wall; and the detail changes to the engine bleed air system. The nacelle inlet cowl lip was protected from undesirable inflight ice accumulations by a thermal anti-icing system utilizing hot engine bleed air.

Ice protection provisions for the engine inlet guide vanes were provided by two hot air systems furnished by the engine manufacturer. The hot air exhausting from the inlet guide vanes provides the thermal energy for anti-icing the engine bullet. These systems were capable of either evaporating all impinging water droplets or providing an ice-free, running-wet surface while passing through (or holding indefinitely within) icing clouds of the intensity and extent prescribed by Part 25 of the Federal Aviation Regulations entitled, "Airworthiness Standards: Transport Category Airplanes."

The details of the nacelle inlet and engine ice protection systems are shown in figures 78 and 79. Engine bleed air for cowl lip anti-icing was extracted from the mid-point of the 13th stage bleed air manifold. The airflow was controlled by a motor-driven cowl anti-icing shut-off valve, by a thermostatic valve located immediately downstream of the shut-off valve (figure 77) and by a flow control orifice in the supply ducting.

The cowl anti-icing supply duct terminates at an "ejector", or jet pump, which injects a mixture of 13th stage bleed air and secondary air (drawn from the nose cowl cavity) tangentially into the nose cowl "D"-duct to ensure uniform circumferential heating and effective anti-icing performance for all areas of the cowl leading edge as shown in figure 80. The "D"-duct, was formed by the cowl leading edge double skin and the "D"-duct closing web and extends completely around the cowl circumference. The inner and outer skins of the cowl leading edge were assembled to form a narrow, constant width air passage through which the hot anti-icing air must flow as it leaves the "D"-duct. The air enters the double skin space through three rows of holes in the outboard portion of the inner skin. Ice formation was prevented on the nose cowl as the air flows inboard and aft around the cowl leading edge. The air then discharges into the nose cowl cavity through small, chemically-milled

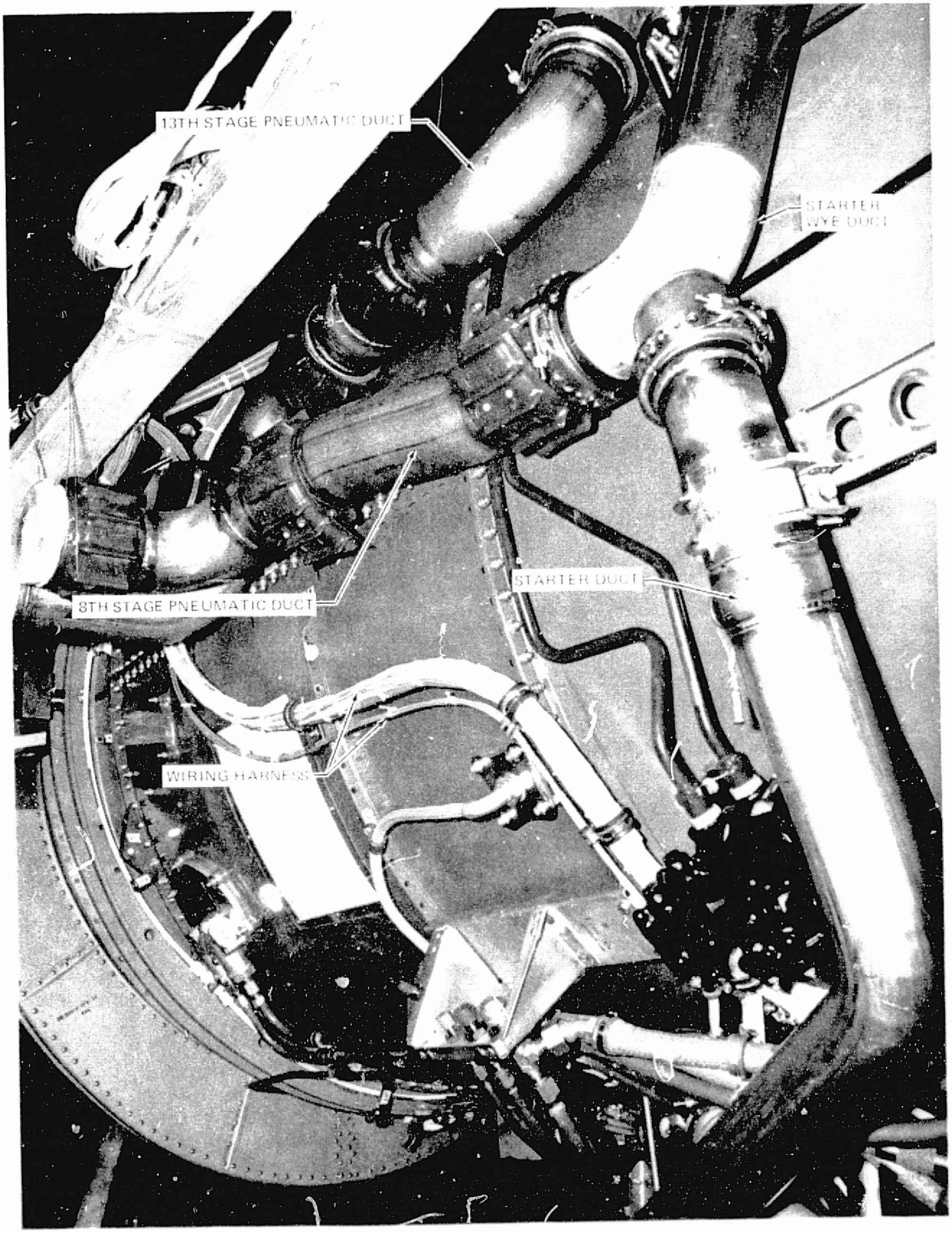

FIGURE 74. LEFT ENGINE PNEUMATIC AND STARTER DUCTING — MOCKUP ENGINE

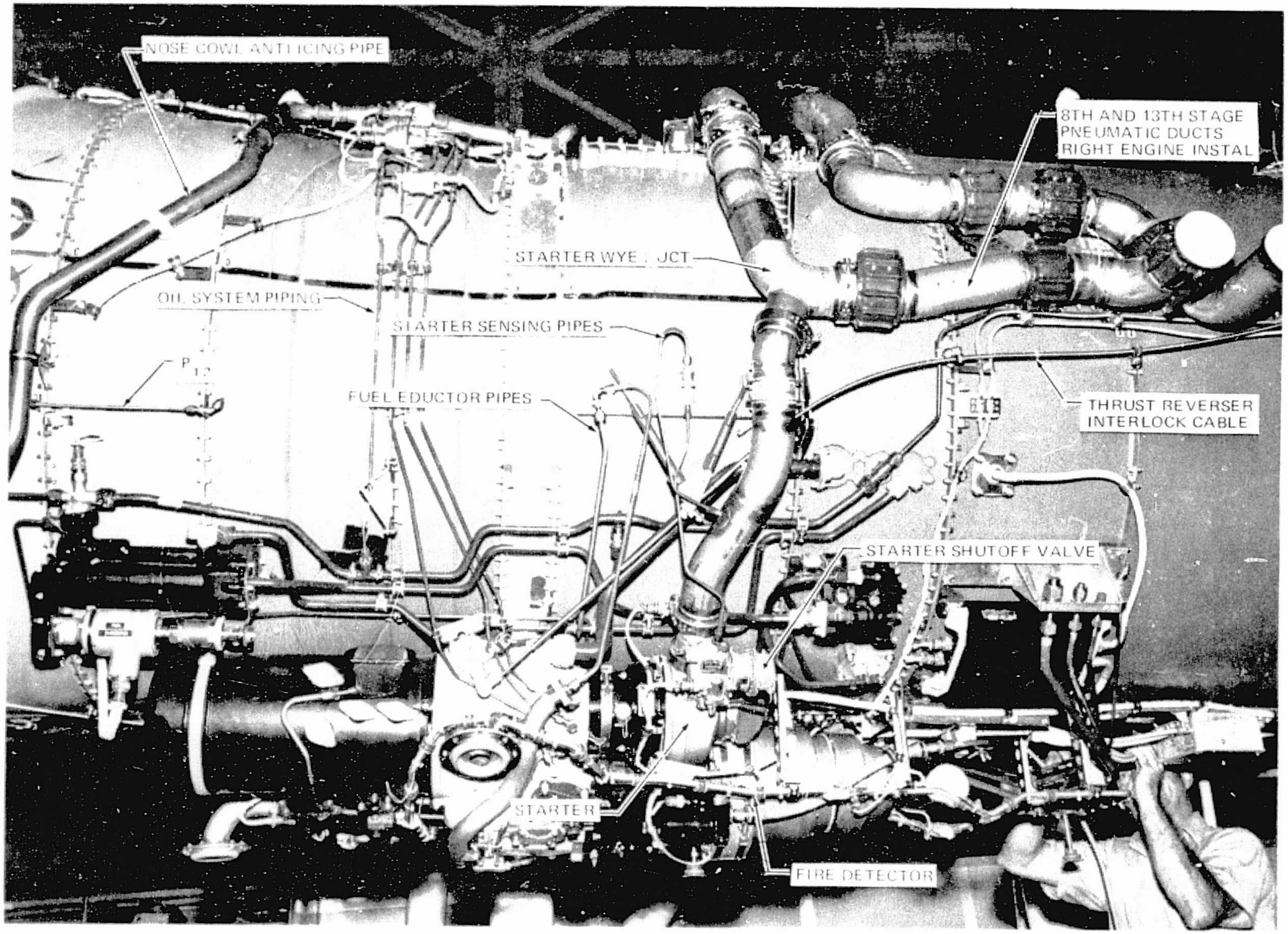

FIGURE 75. MOCKUP ENGINE – LEFT SIDE

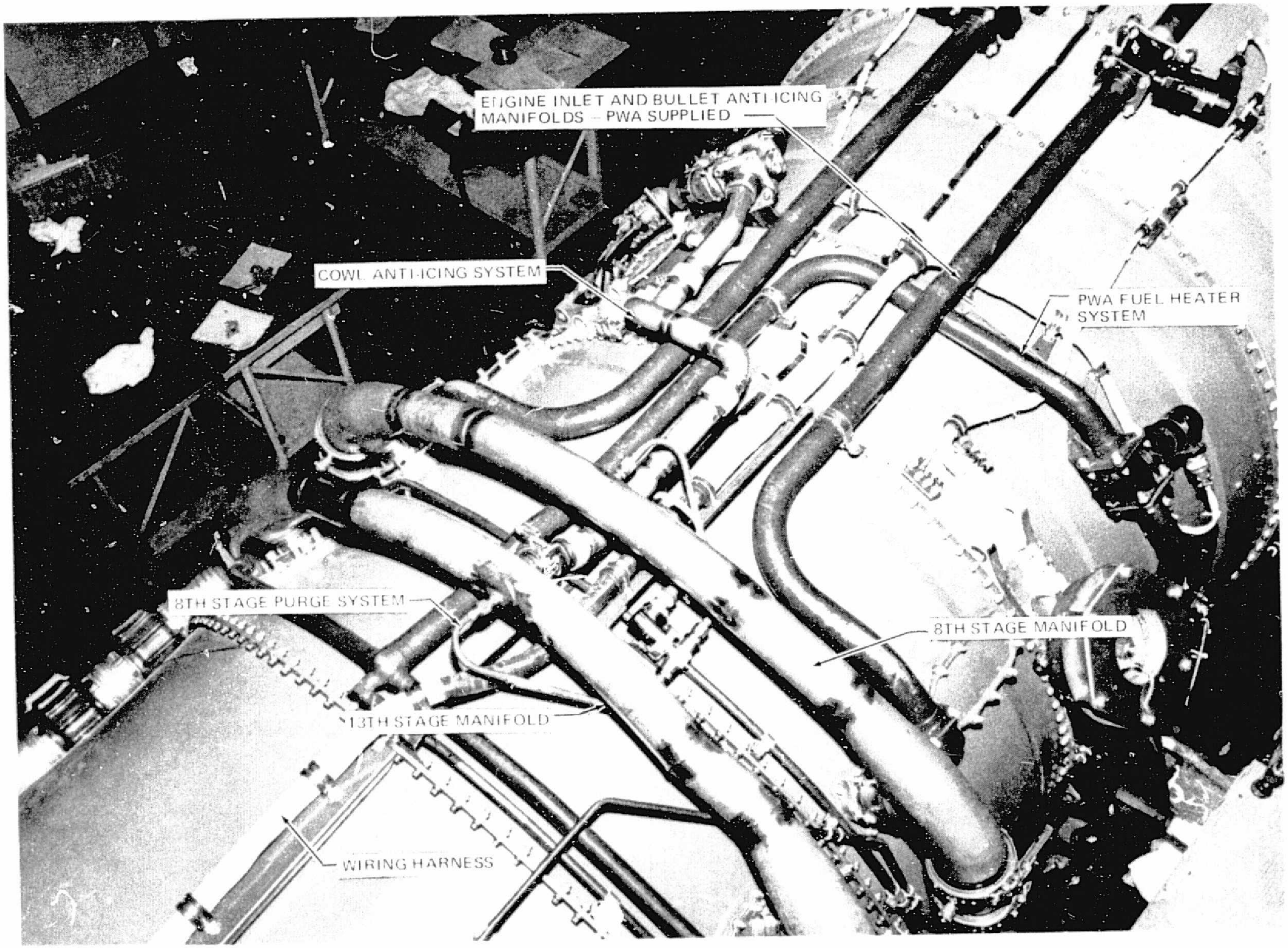

FIGURE 76. ENGINE BLEED AIR DUCTING

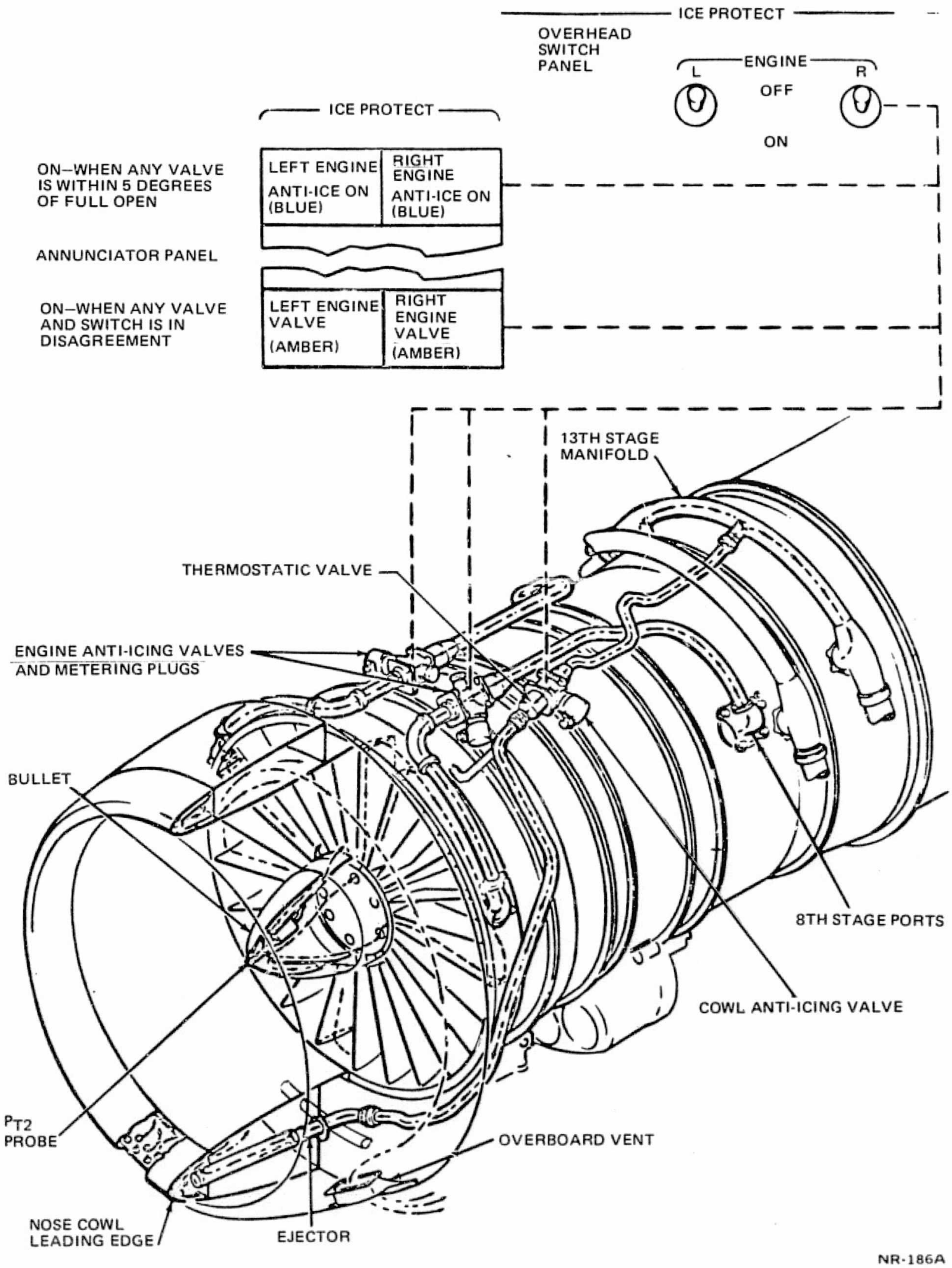

FIGURE 77. NACELLE INLET AND ENGINE ICE PROTECTION SYSTEMS

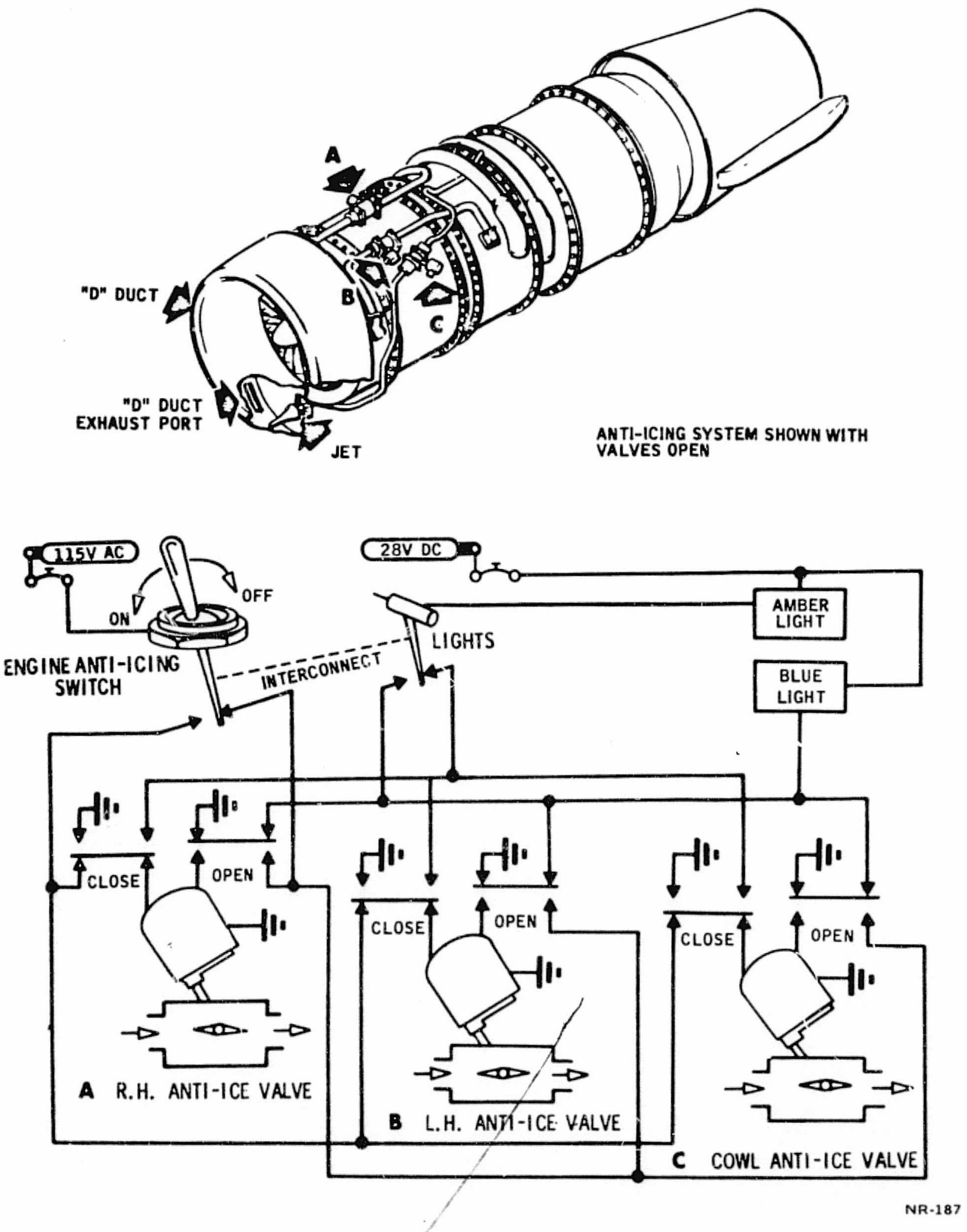

FIGURE 78. NOSE COWL AND ENGINE ICE PROTECTION SYSTEMS SCHEMATIC

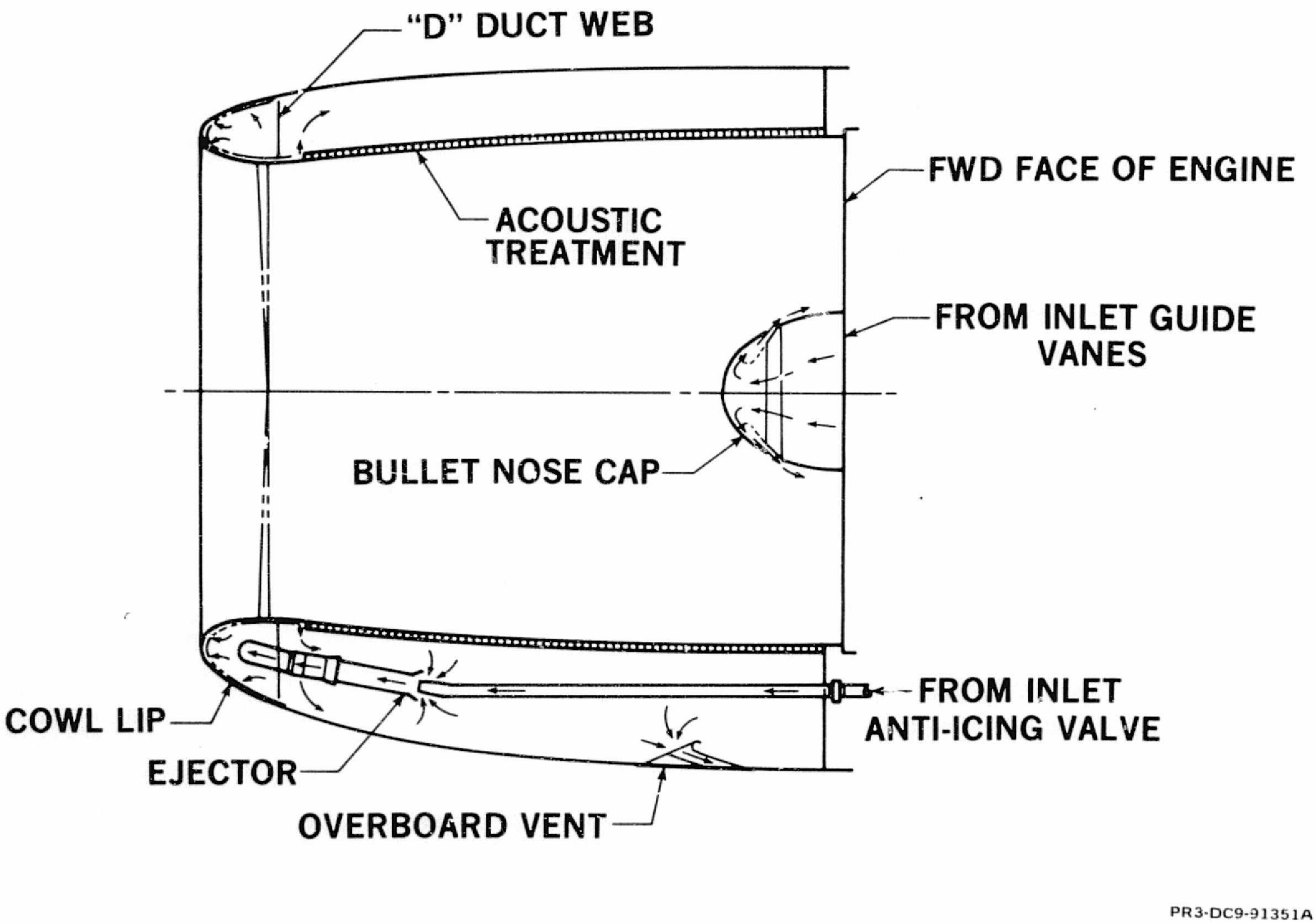

FIGURE 79. NACELLE INLET AND BULLET ICE PROTECTION SYSTEM

streamwise, airflow passages in a spacer located between the inner and outer skins of the inlet duct wall. The air exits overboard through an opening at the bottom of the cowl.

The entire double-skinned region, termed the primary heated area, was provided with sufficient heat to evaporate essentially all impinging water droplets. The surface of the nacelle wall from the end of the chemically-milled passages to the engine fan face, termed the secondary heated area was protected from run-back ice formation (if any) by heat conduction through the metallic acoustically treated inner wall from the hot exhaust air inside the cowl cavity.

The engine inlet guide vanes were anti-iced by a system supplied by Pratt and Whitney. Engine bleed air was extracted from the 8th stage of the engine compressor and conveyed to a manifold connecting the outer ends of the inlet guide vanes by the right and left engine anti-icing systems (figure 77). Each system, which services half of the inlet guide vanes, includes an anti-icing air shut-off valve, an anti-icing metering plug, and the necessary interconnecting ducting. The metering plugs limit the flow of anti-icing air delivered to the inlet guide vanes. The air exhausting from the inner ends of the inlet guide vanes is used to anti-ice the bullet. The air entering the bullet cavity blasts against the bullet nose, flows aft along the inner surface of the bullet nose cap, and exits into the main engine airflow as shown in figure 79.

The shut-off valves for the nacelle inlet and engine ice protection system were controlled by switches located on the ice protection panel in the flight compartment. A single switch controls three-anti-icing shut-off valves for each nacelle: one valve for the nacelle inlet cowl, the others for the inlet guide vanes and bullet (figure 78). Amber disagreement lights (one for each engine) indicate any discrepancy between the selected and actual shut-off valve positions. Blue lights show when any valve was within 5 degrees of full open.

Routing and support design of the cowl anti-icing ducts, shutoff and thermostatic valves, was similar to the DC-9. Bleed air was extracted from the 13th stage bleed air manifold, routed thru a modified DC-9 duct (containing three flexible joints), the valves, and a one piece tube that proceeds down and forward on the left side of the engine to a connection at the bottom centerline of the nose cowl aft bulkhead. Development of this system included installation of the modified DC-9 duct and valves and routing and clipping of the one piece forward pipe to the engine. See figures 75, 76, 81 and 82.

Nacelle cooling and ventilation. - Cooling and ventilating air for the accessory compartment was provided by air inlets located in the pylon leading edge and lower access door and with an outlet located in the aft end of the upper access door. Natural convection provides adequate ground cooling. System design was identical to the production DC-9 except for the location of pylon air inlet. See figure 42 and 82.

Drain system. - To prevent engine and gear box oil contamination due to a seal failure, overboard drains are installed for the engine fuel pump, hydraulic pump, starter, and constant speed drive input drive pads. To prevent fluid

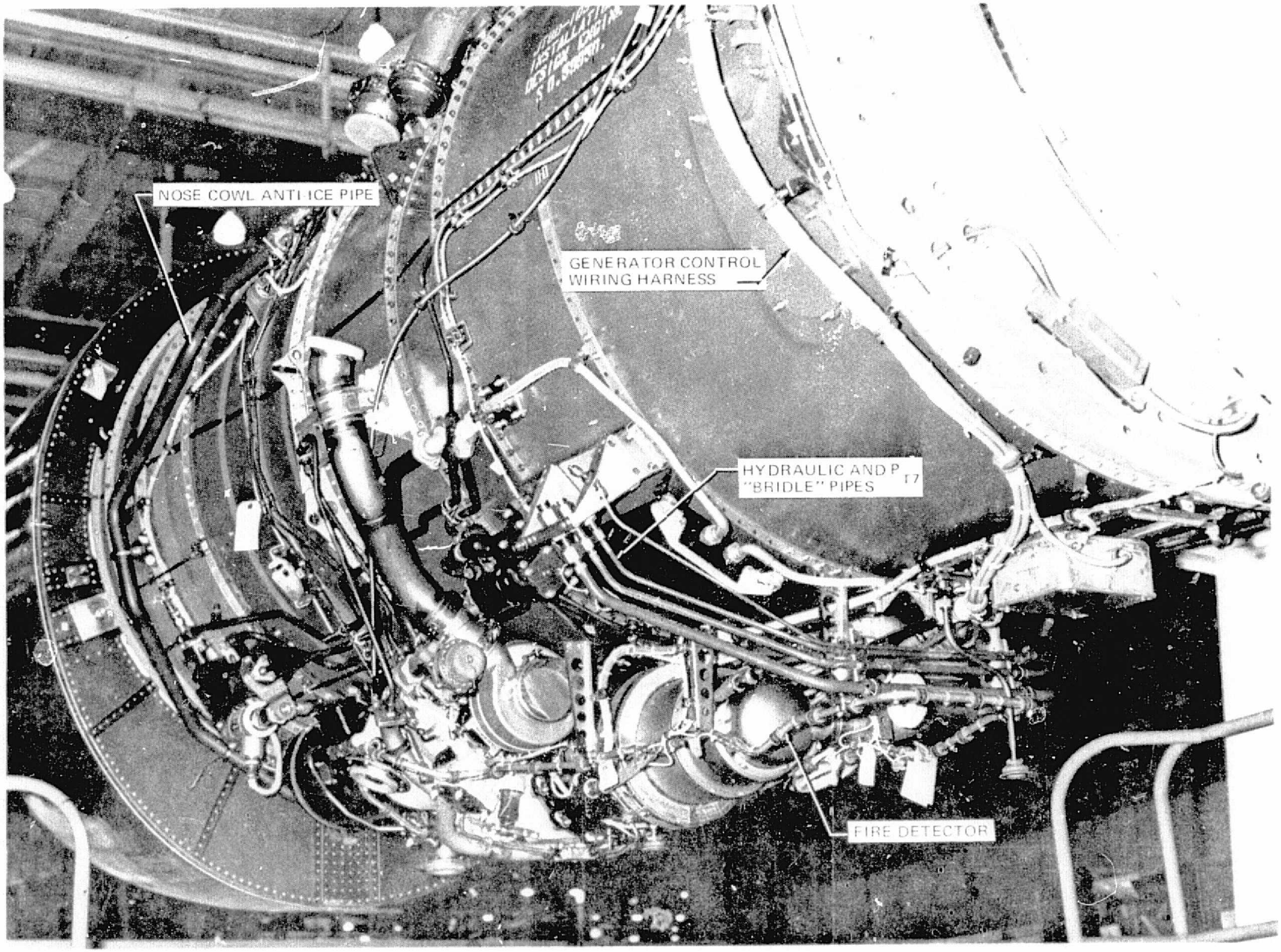

FIGURE 80. MOCKUP ENGINE – SYSTEMS DEVELOPMENT
LOOKING FORWARD – LEFT-HAND SIDE

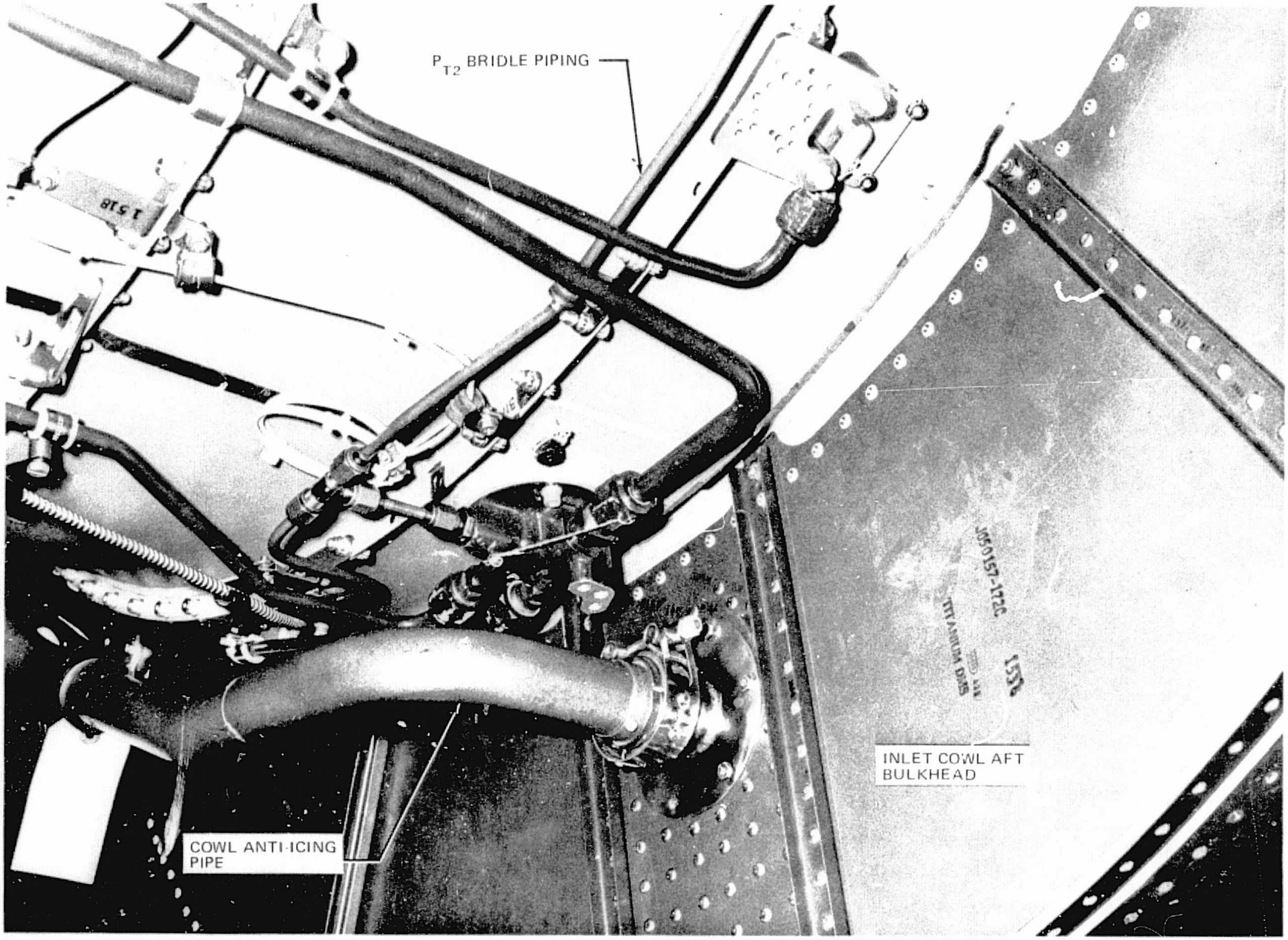

FIGURE 81. MOCKUP ENGINE – COWL ANTI-ICING AND P_{T2} PIPING

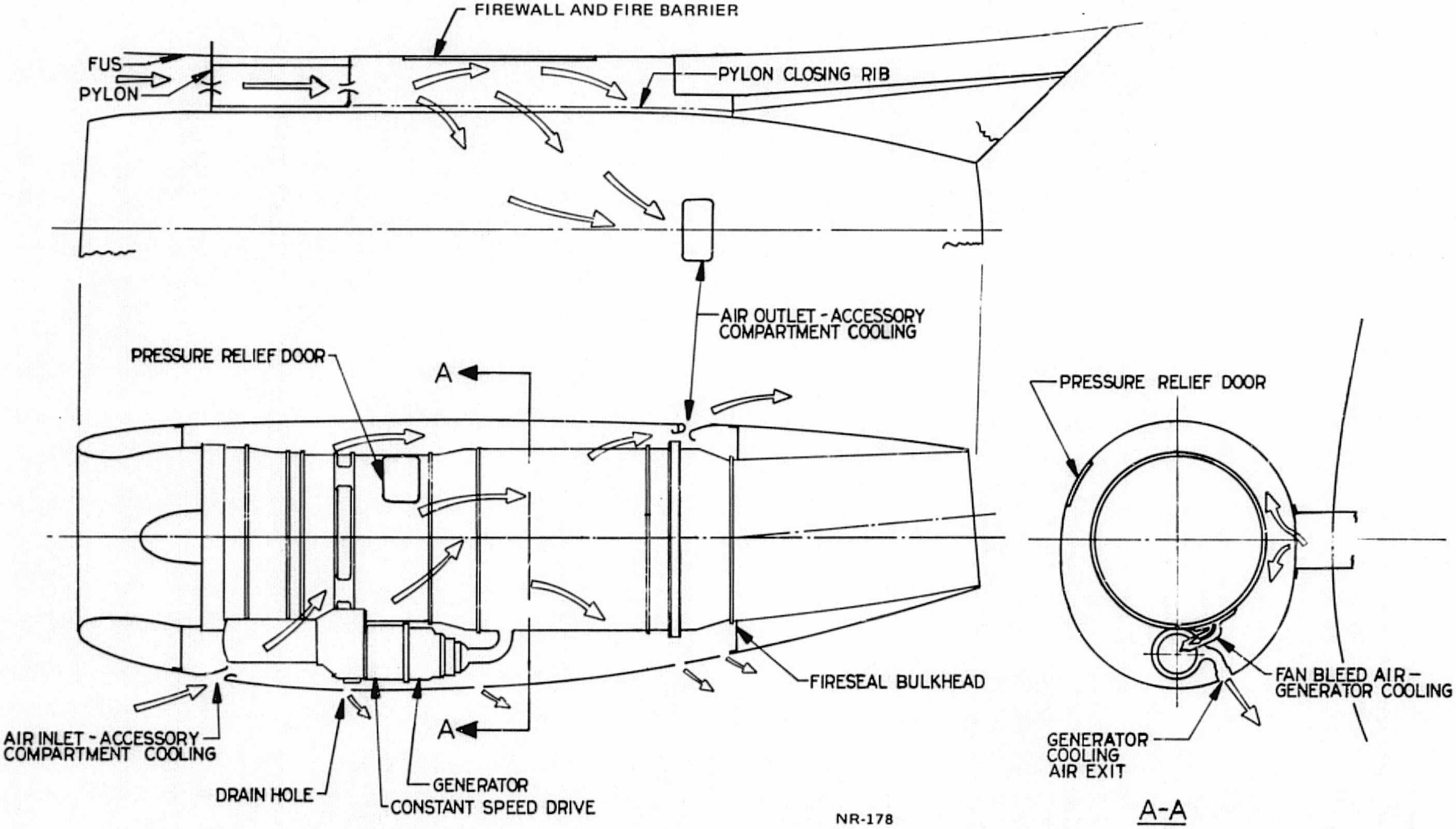

FIGURE 82. REFAN NACELLE COOLING SYSTEM

leakage into the accessory compartment drains are installed at the oil scupper overflow and engine combustion chamber outlet. Three 9.65 mm (0.38 in.) diameter holes located along the lower access door bottom centerline allow drainage of accumulated water. The drain configuration was identical in design to the production DC-9 installation.

Oil system. - The JT8D-109 lubrication system was identical to that of the basic JT8D-9 engine. Each engine was supplied with a complete and independent oil system, as shown schematically in figure 83. The oil system, furnished by the engine manufacturer, consists of the following major components: oil pump, oil filter, fuel/oil heat exchanger (oil cooler), scavenger pumps, and an oil tank. A small access door was provided in the lower main access door for oil tank filling and viewing the oil quantity sight gauges. System operating conditions were displayed in the flight compartment by oil quantity pressure, and temperature indicators. Engine lubricating oil was cooled by the fuel/oil cooler mounted on the forward left side of the engine. The fuel/oil cooler accomplishes cooling by using engine high-pressure fuel as a heat exchange medium.

Since the engine was supplied with a complete and independent oil system the airframe manufacturer must supply cockpit indication for pressure, low pressure warning, and oil filter differential pressure. The oil pressure transmitter, low oil pressure warning switch, and oil filter differential pressure switch, were installed on engine brackets on Flange E upper left hand quadrant. Six new pipes were developed between above units and vent connections on the engine gearbox as shown in figure 75.

Starting and ignition system. - The effective rotor polar moment of inertia at the starting pad for the JT8D-109 did not change due to the Refan engine modification. Therefore, the engine starting system remained unchanged, except for redevelopment of starter ducting as shown in figures 74 and 75.

The engine starting system converts pneumatic power into shaft torque for initial rotation of the high-pressure compressor (N_2) rotor. The system, shown schematically in figure 84, consists of an air turbine starter, solenoid actuated starter air shut-off valve (with pressure regulator), a control switch, and a starter valve position indicating light. The starter and an air shut-off valve were located on the forward lower left side of each engine. The control switch was located on the overhead switch panel, and the amber indicating light is located on the annunciator panel in the flight compartment. The starting system receives electrical power from the 28-volt dc transfer bus.

Pneumatic pressure to operate the starter may be obtained from any of the following sources:

- An external pneumatic supply connected to the fuselage ground pneumatic connector.
- Airplane pneumatic system when one engine is running (cross-feed starts).
- Auxiliary power unit pneumatic supply.

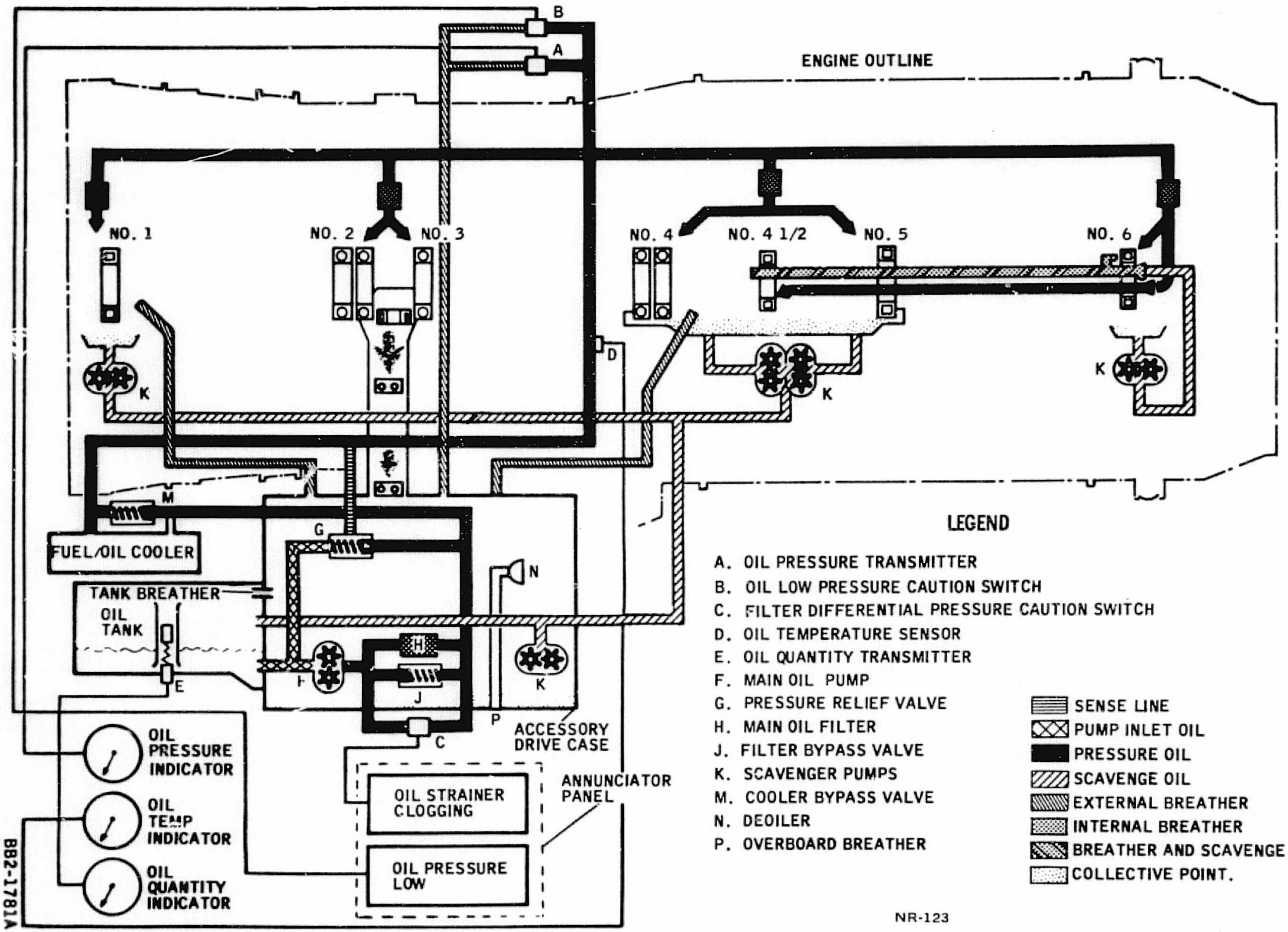

FIGURE 83. DC-9 AND REFAN ENGINE OIL SYSTEM

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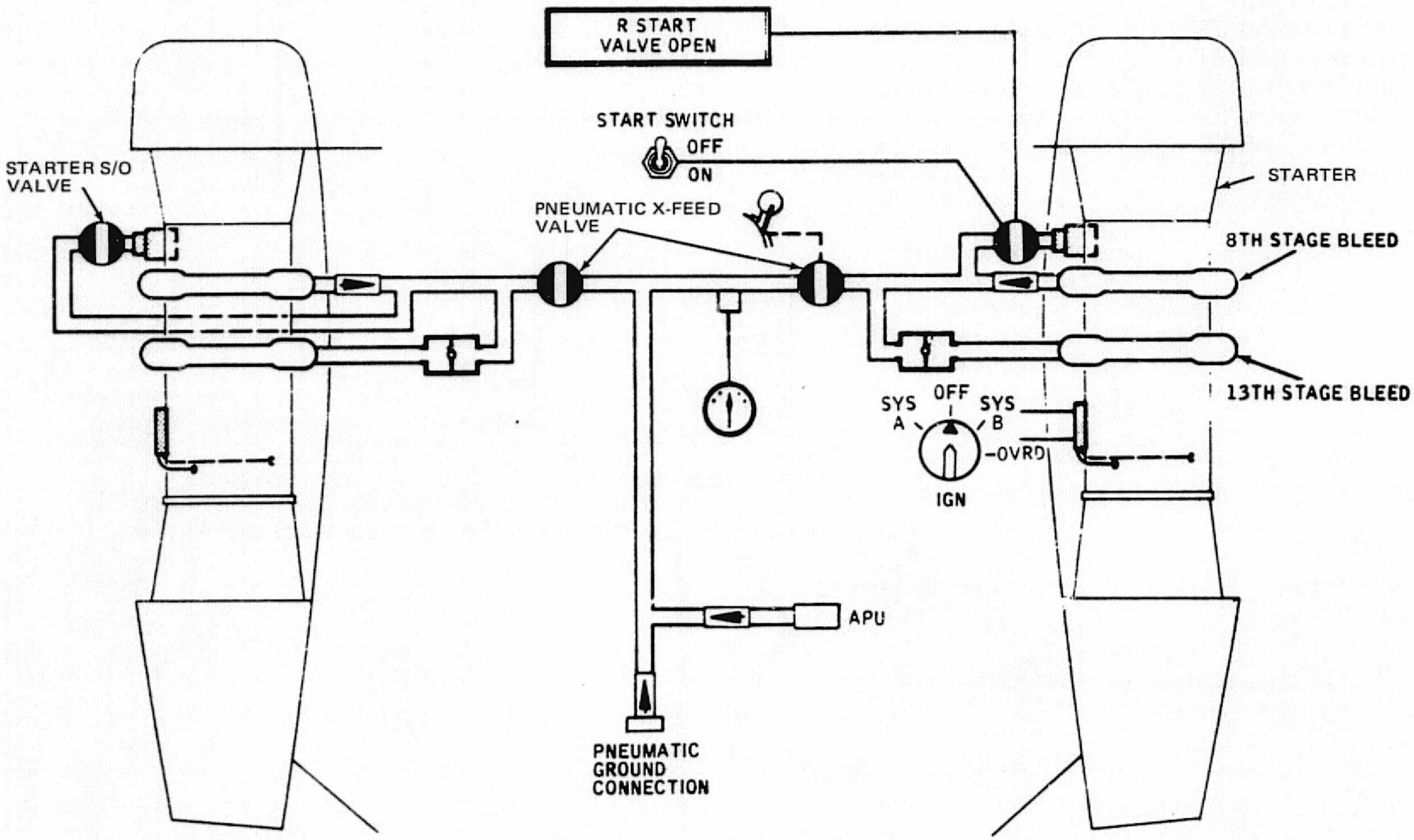

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FIGURE 84. ENGINE STARTING SYSTEM

The ignition system was a dual high energy ac type. This system was used for ground and in-flight starting, and in-flight flameout protection as required.

Three new pipes were developed for the pneumatic sensing system as shown in figure 75. Eighth stage air was bled from the starter duct to a filter, then thru a common pipe into the shutoff valve inlet port.

Electrical system. - A 40 KVA, 3 phase, 120/208 volt, 400 cycle generator was mounted on each constant speed drive and was the primary source of electrical power for the airplane. Generator cooling air is supplied by the engine fan air. Cooling air was drawn from a port in the fan duct, through flexible bellows, to the generator cooling air shroud. Air was then exhausted overboard through the exit in the lower engine access door. See figure 85. The DC-9 generator and its cooling system hardware were retained for use on the Refan installation.

On the mockup engine electric wire routing and clipping started with a production harness from Rohr modified by eight feet of wire added to the fire wall disconnect end. The added wire length was used to provide for the increased size of the engine and variations in routing.

Development of the miscellaneous (largest-most complex) harness started with placing it on top the mockup engine and establishing an index point near the forward end. Enough wire is drawn through the index point to allow for routing clipping and terminating of each plug. Pattern of the new routing and clipping of the forward part of the mockup engine followed very closely production routing.

Wire routing developed on the aft section of the mockup engine departed radically from the production pattern because of interference with hot bleed air piping. A new breakout point from the main wire bundle was established and all wires to this section come down the right side. A new support bar for these wires was added to the top, right side and contoured to the diameter of the engine.

Generator control wire harness followed the general routing pattern established by the miscellaneous wire harness. Generator power cables followed a path almost identical to that established in production, except for deviation because of new greater diameter. For these harnesses the ability to use the same wire harness for either right or left engine installation was retained. Trimming the harnesses for installing the fire wall terminating plugs was not done until the mockup engine was trial fitted to the airplane. Installation of thrust reverse wire harness was in an area of all new structure, so the entire harness was developed new. Figures 74, 75, 76, 80 and 86 illustrate wire routing and clipping.

In the aft fuselage it was determined that development of wire routing and clipping could be contained in the local area of the fire wall feed thru's to each engine. Existing wire harnesses were not affected, but routing was modified by new clipping supports to accommodate the new fire wall structure.

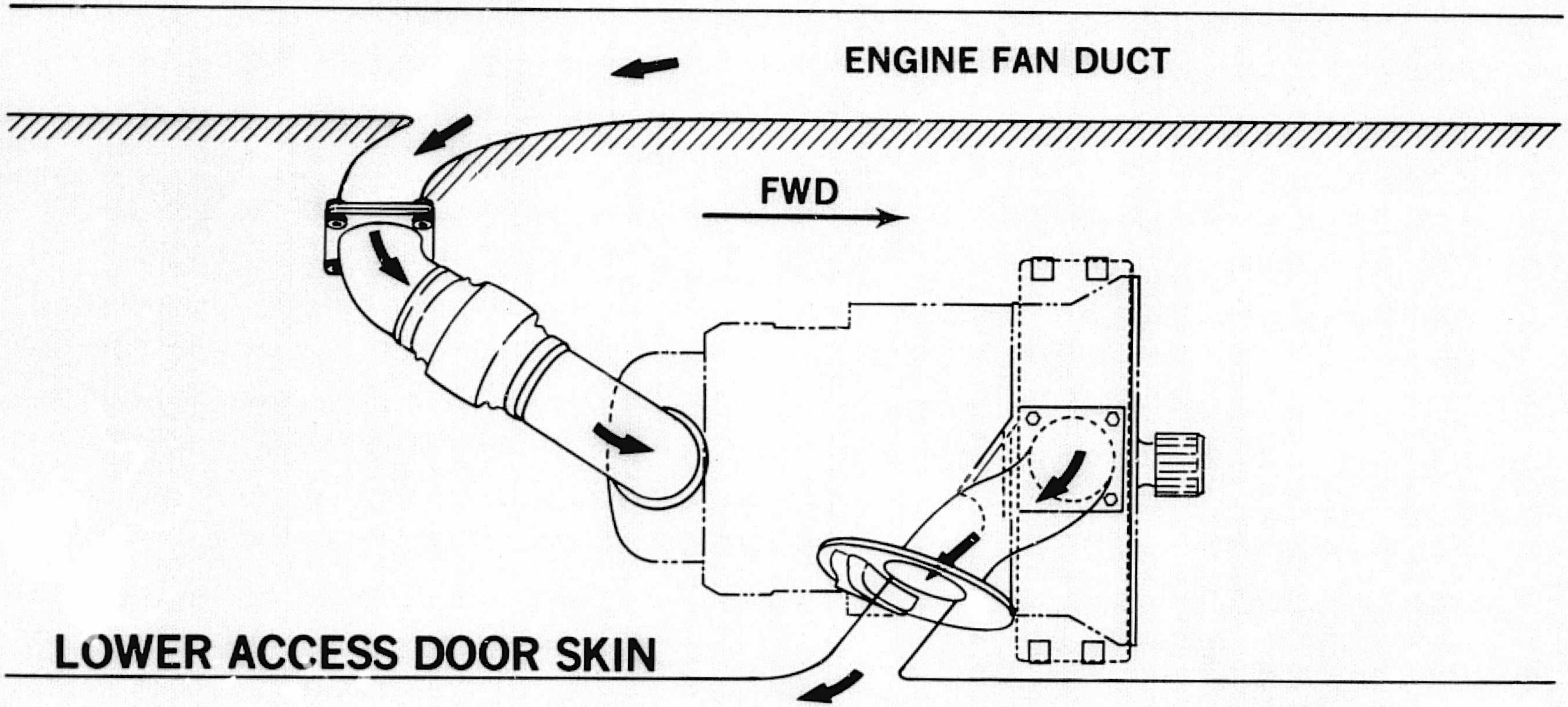

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FIGURE 85. SCHEMATIC – GENERATOR COOLING

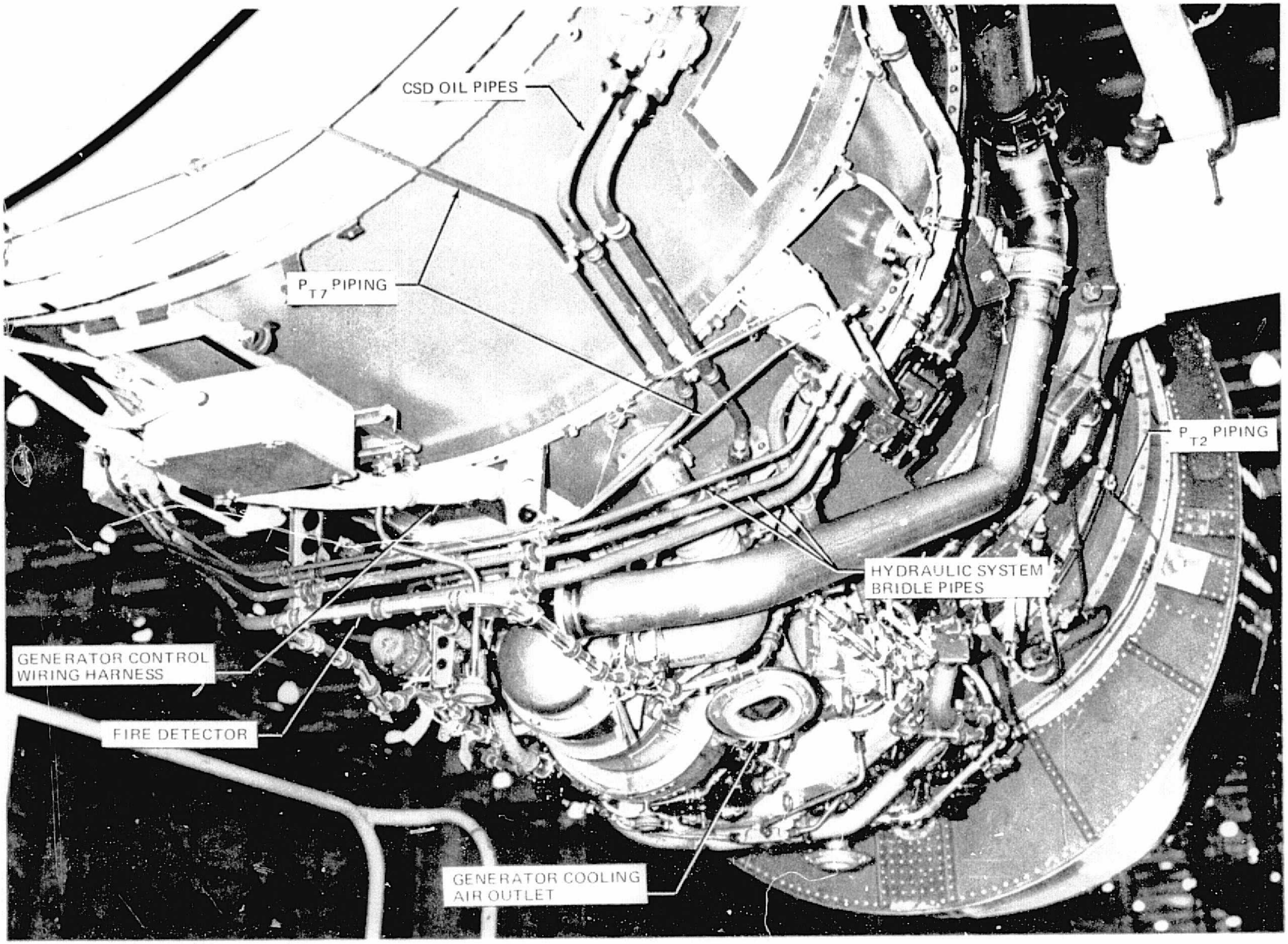

FIGURE 86. LOOKING FORWARD – RIGHT-HAND SIDE

The fire detector loop installed on the Refan apron used the DC-9 production harness. By adjusting the routing to conform to the new apron configuration, the clipping was modified to provide full support such that no length change was required on the harness.

Constant speed drive. - A constant speed drive (CSD) was installed on each engine to provide a means of driving the ac generator at a constant speed regardless of engine speed and generator electrical load. The CSD is installed on an adapter pad at the lower aft centerline of the engine gearbox. Oil outlet temperature, oil temperature rise indications, and oil low pressure lights are provided for cockpit indication. The CSD may be disengaged in flight if a mechanical or electrical failure occurs.

CSD oil is cooled by an air/oil cooler installed in the right side of the fan case just forward of flange K and below the horizontal centerline. The system is shown schematically in figure 87.

The complete DC-9 CSD installation was retained except for two new "in" and "out" cooler pipes. Routing and installation of these pipes are shown in figure 86.

Hydraulic system. - The Refan engine hydraulic system was identical to the DC-9 and uses the piping "bridle" arrangement so that the engine to pylon connections can be readily made to either side of the engine. For this system the three "bridle" pipes were routed across and under the engine as shown in figures 81 and 86. The pressure, suction, and case drain hoses shown in figure 88 are identical to the DC-9.

Fuel system. - The Refan fuel system remained schematically unchanged, as shown in figure 89, from the production DC-9. Five new pipes were developed to complete the "bridle" arrangement for the fuel eductor (jet pump) system. See figures 75 and 88.

Engine controls. - The mechanical engine controls consist of a throttle and thrust reverser control system and a fuel shutoff system as shown in figures 56, 90, and 91. Thrust reverser control design is described on page 65.

1. Throttle Control

   The Refan throttle control system remained unchanged from the DC-9. Development was accomplished by installing the bill of material hardware for a fit and clearance check.

2. Fuel Shutoff

   The DC-9 push pull cable between the aft control sector and the engine cross shaft was replaced with a linear actuator as shown in figure 92. The actuator receives its signal to open or close from a switch in the cockpit fuel shutoff lever mechanism. See figure 91. Development of this system was accomplished by installing the bill of material hardware for a fit and clearance check.

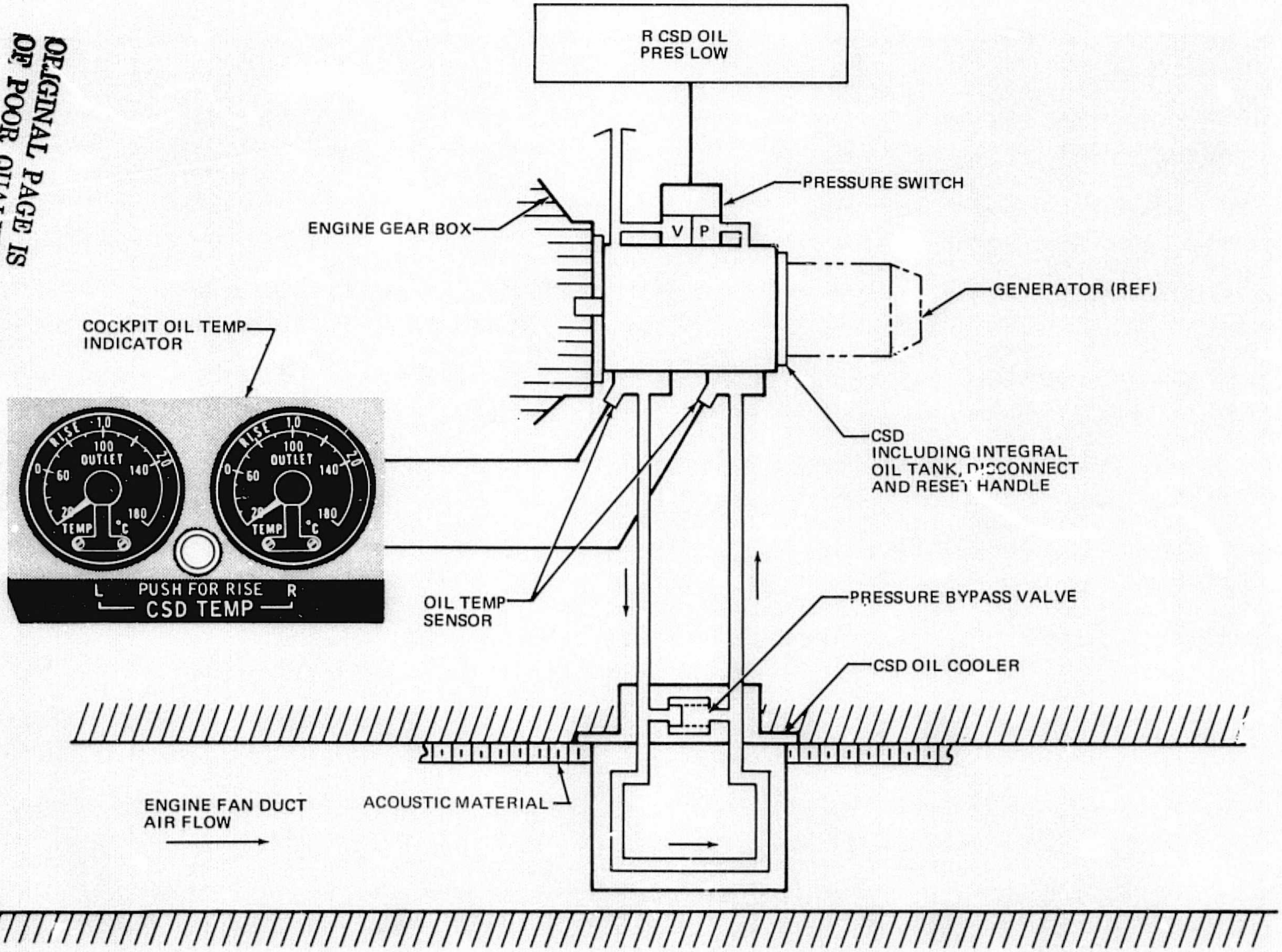

FIGURE 87. DC-9 AND REFAN CSD OIL SYSTEM

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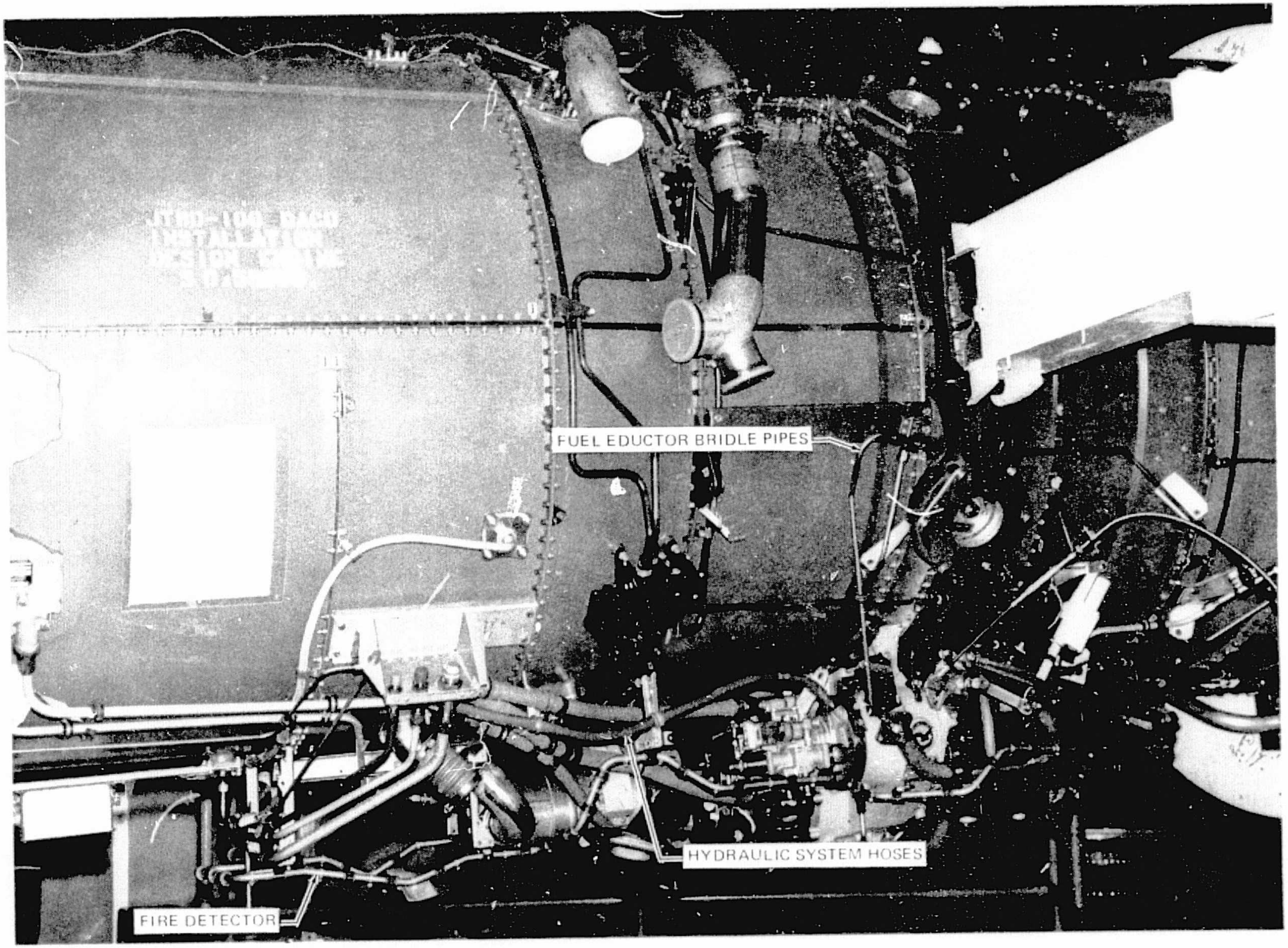

FIGURE 88. RIGHT-HAND SIDE

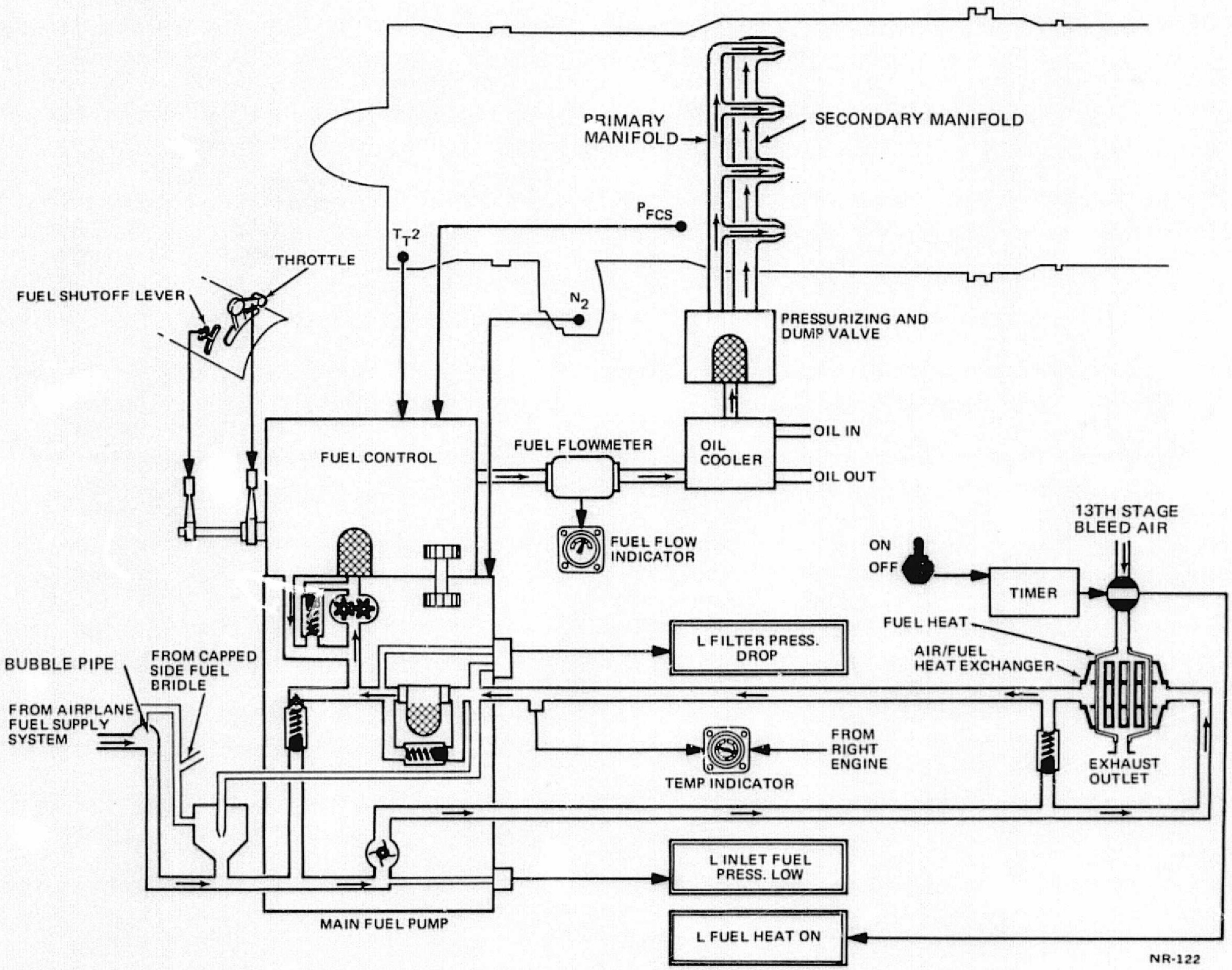

FIGURE 89. DC-9 AND REFAN ENGINE FUEL SYSTEM

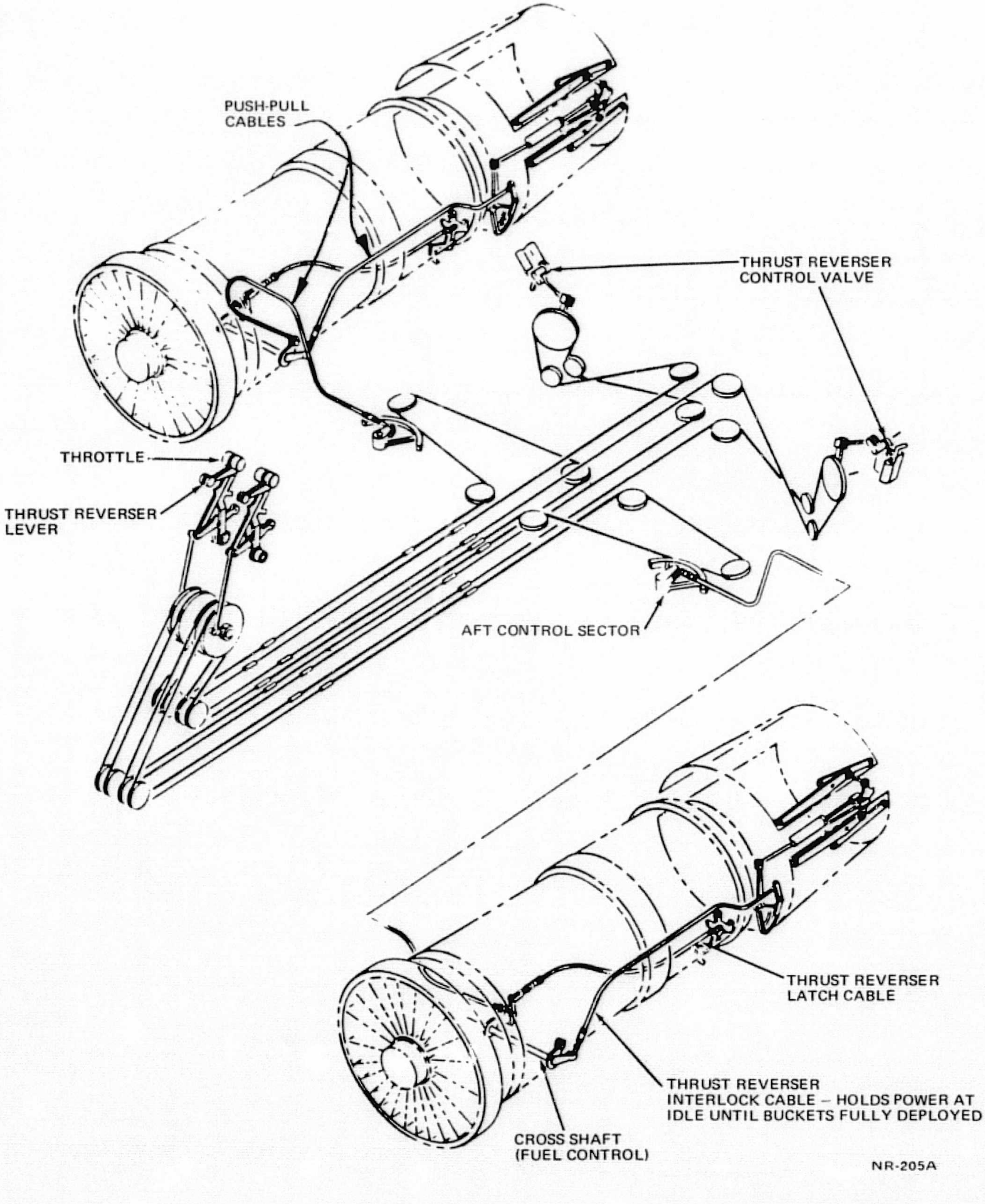

FIGURE 90. DC-9 AND REFAN THROTTLE AND THRUST REVERSER MECHANICAL CONTROL

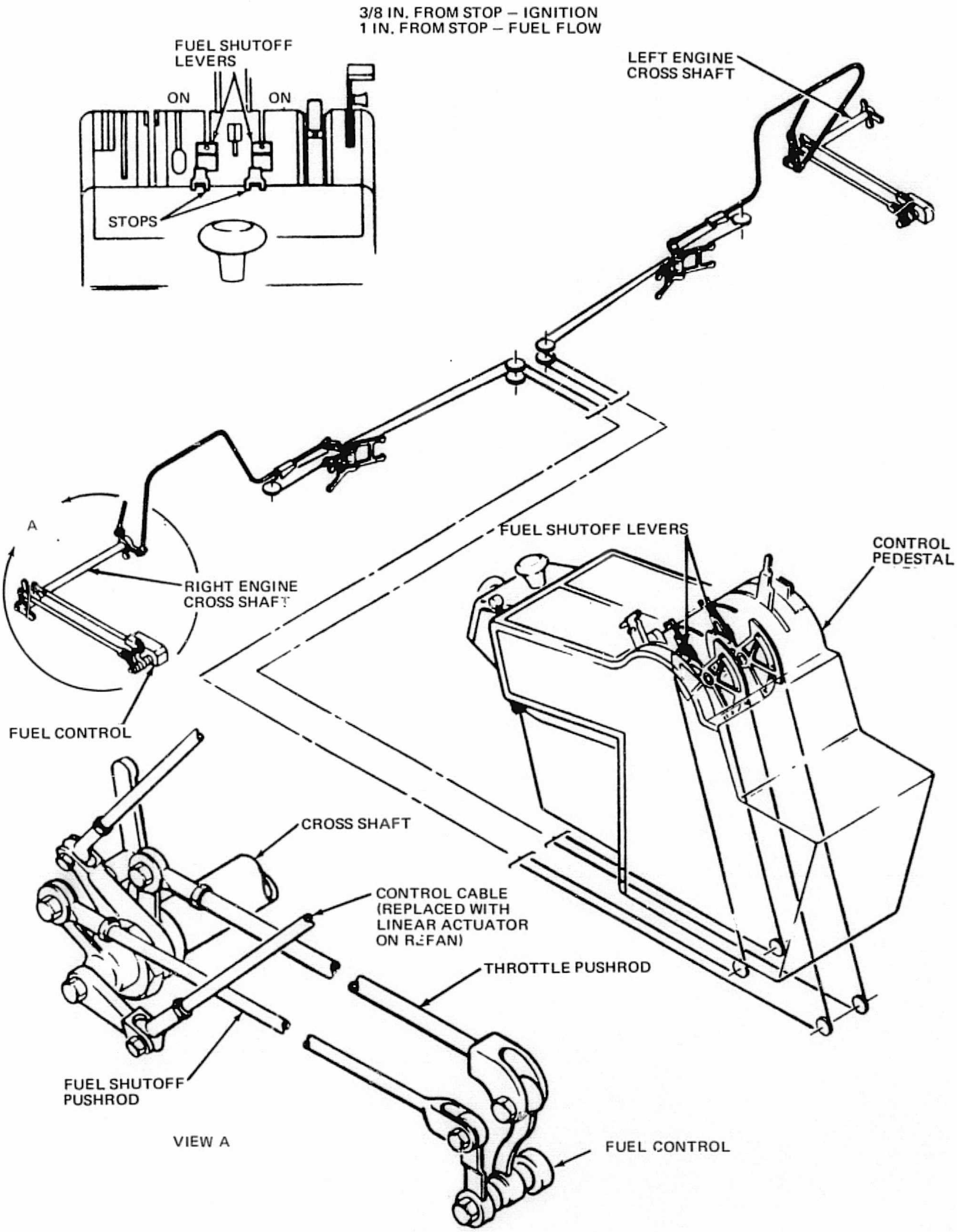

FIGURE 91. DC-9 AND REFAN FUEL SHUTOFF SYSTEM

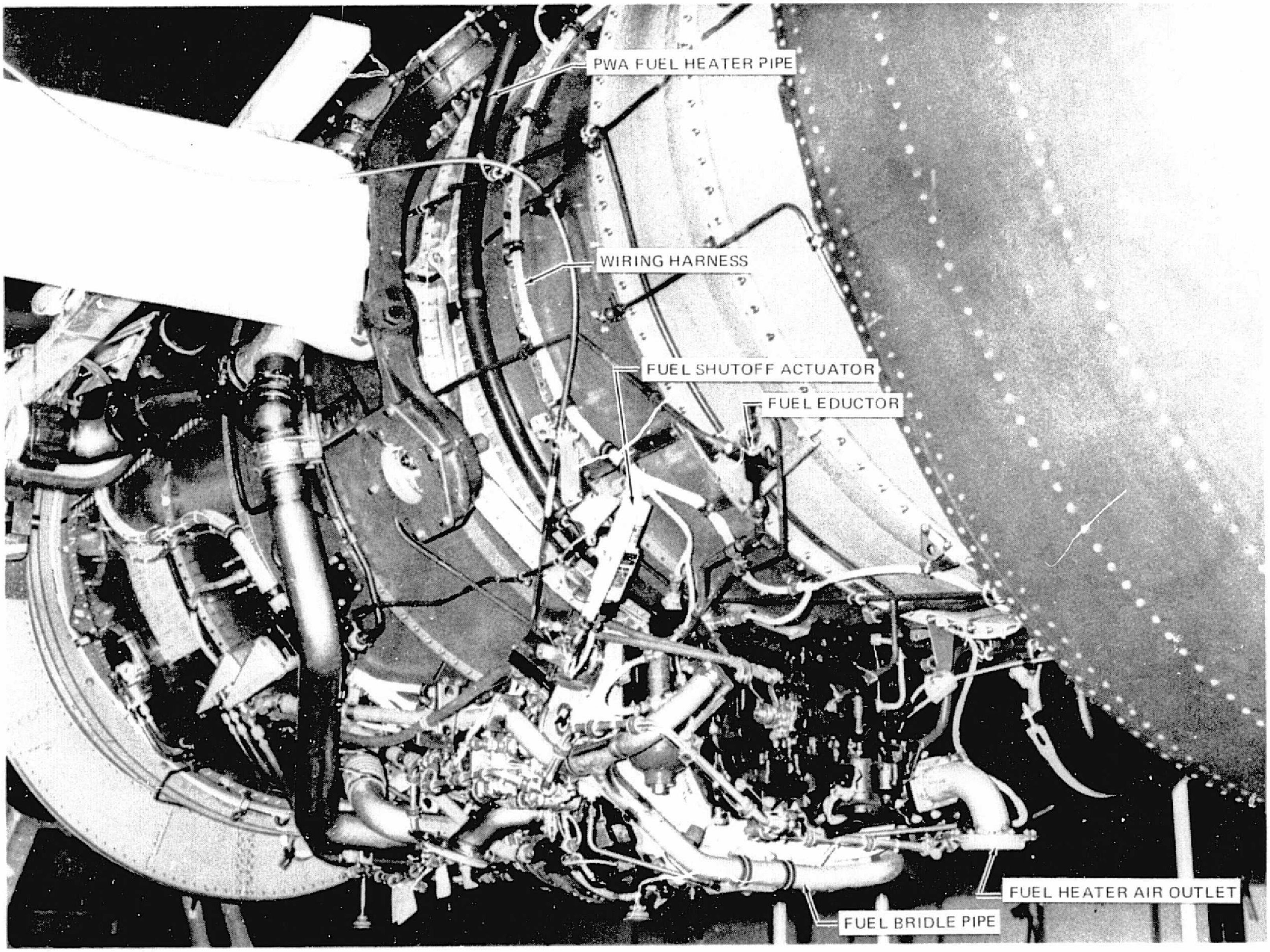

FIGURE 92. LOOKING AFT – RIGHT-HAND SIDE

3. Thrust Reverser Interlock

Interlock control development required the installation of the bill of material cam mechanism in the exhaust duct forward segment and installation of the duct segment on the mockup engine in order to determine the length of the vendor supplied flexible cable. All bill of material parts were installed for a fit and clearance check. See figures 36 and 75.

Thrust Reverser Door Latches

The development of both the upper and lower latch installations was done in a manner identical to the interlock system.

Engine instrumentation. - Installation of the Refan JT8D-109 engine resulted in minimal changes, such as redevelopment of piping and wire routing and clipping, for the DC-9 indicating systems. Figure 93 shows schematically the basic engine instrumentation.

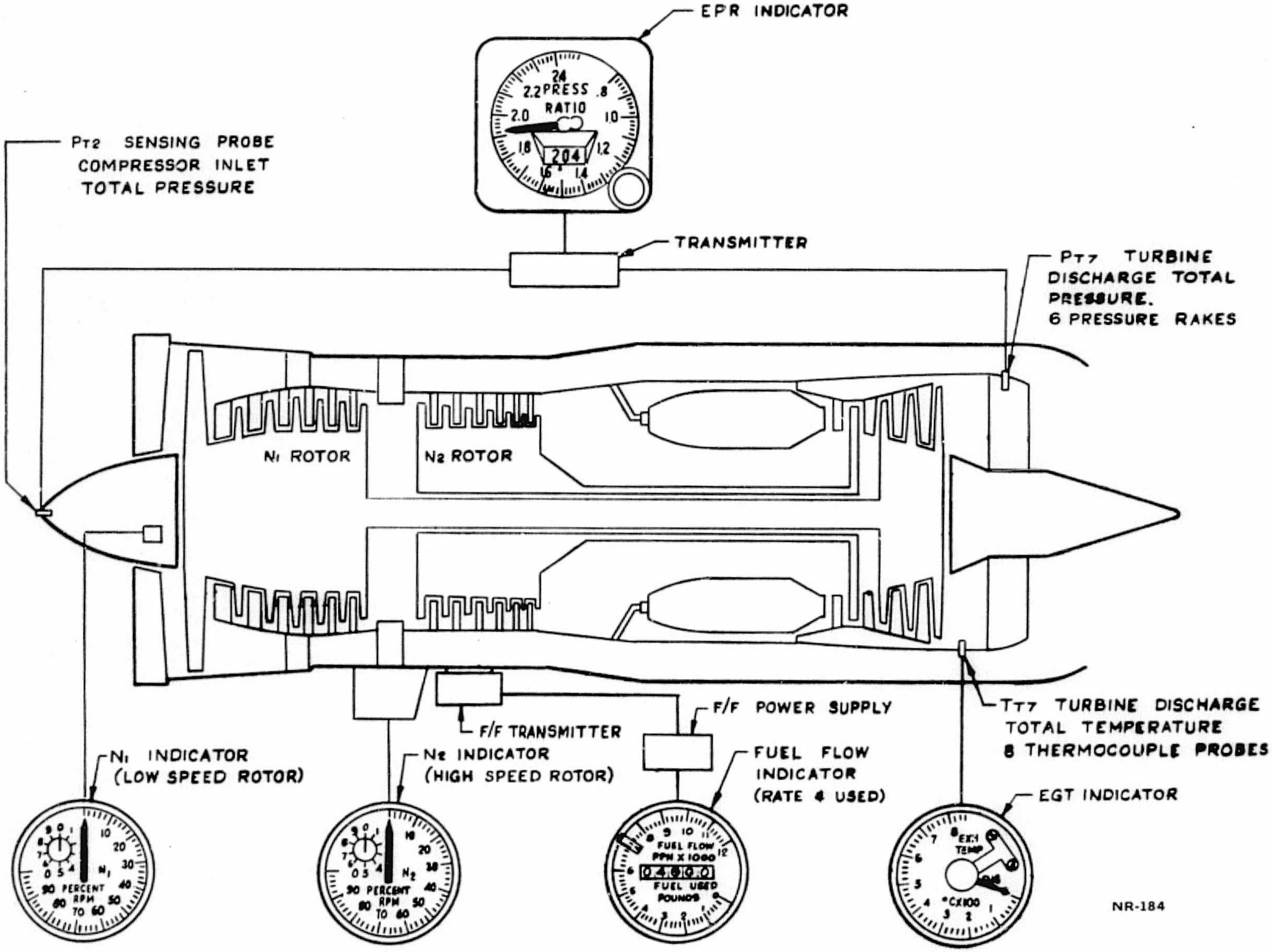

FIGURE 93. JT8D-109 ENGINE INDICATING SYSTEM

Fire Protection

Fire protection philosophy for Douglas commercial aircraft is first to prevent occurence of fire and then containment of the fire. Measures are provided that meet or exceed FAA requirements. Any compartment in which a failure can bring together a combustible material and an ignition source is treated as a fire zone with attendant shielding, extinguishing, and detection provisions for fire control. Barriers and seals are employed for isolation and containment and to keep combustibles from ignition sources.

Pylon fire protection. - Pylon fire protection is described on page 20.

Nacelle fire protection. - The space surrounding the engine containing the engine accessories and the engine fuel system is a fire zone. Fuel leakage in this area is safeguarded by the flow of air provided by the nacelle cooling and ventilating system and the fluid drain system. This zone is bounded by fire proof bulkheads at the nose cowl, tailpipe and the pylon.

The fire extinguishing system, shown in figures 94 and 95 consists of two agent containers equipped with one electrically actuated discharge head for each compartment served. One discharge head from each container was joined through a flow control "wye" to a single discharge line for its respective compartment. The "wye" arrangement provides a two-shot high rate discharge of fire extinguishing agent without the use of directional control valves and without loss of agent to a previously discharged container.

The two agent containers were installed in the unpressurized aft fuselage compartment, and were charged with non-toxic bromotriflouromethane (CF_3BR). The slight increase in the volume of the fire protected zone requires 10 lb. (4.54 Kg) of agent (was 8.4#) (3.81 Kg) using the same container. Each container was equipped with a helical-wound bourdon tube type pressure gauge and a thermometer which reads internal agent temperature for accurate agent pressure correction due to temperature. Both the pressure gauge and the thermometer were replaceable without loss of agent. Indicator lights, actuated by the pressure switch, were provided in the cockpit and on the external APU control panel for each bottle.

Two completely separate low-voltage, low-impedance DC, continuous element fire detector systems are installed in each nacelle and pylon, as shown in figures 96 and 97. The corresponding elements in each system were installed on a single rugged support tube attached with a minimum number of quick release fasteners. This mounting arrangement minimizes susceptibility to damage by providing a high degree of mounting protection and also provides easy removal and installation of the complete system as a subassembly. Each element was in close proximity to the other. With this arrangement, a fire will affect both systems while a short-circuit will normally affect only one. Both systems must actuate before a fire warning is given. Amber lights were provided for the detection of a single system short.

Since the entire DC-9 engine mounted fire detector was used for the Refan installation, development consisted of installing the detector support tube

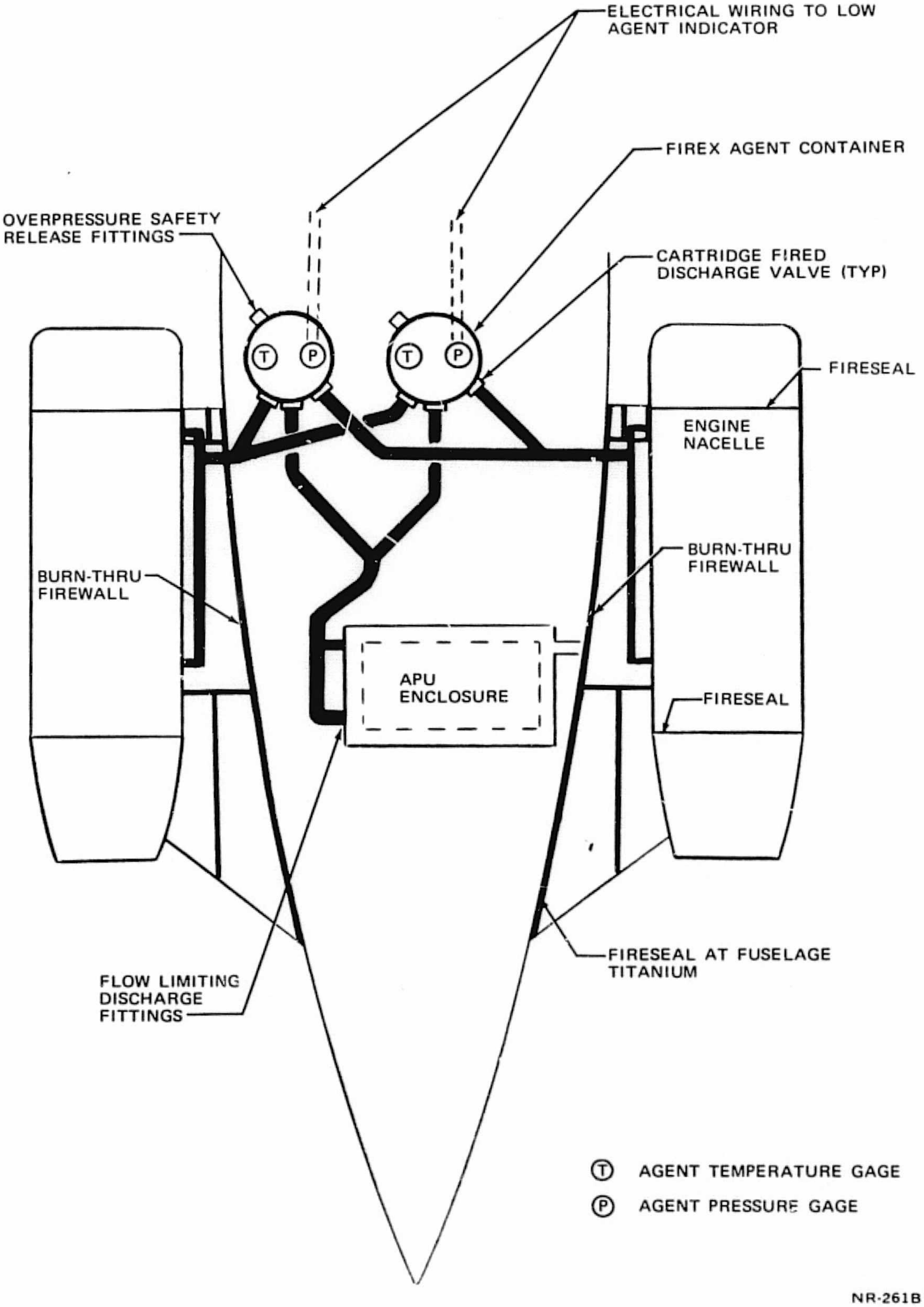

FIGURE 94. DC-9 REFAN JT8D-109 ENGINE FIREWALL AND FIREX SYSTEM

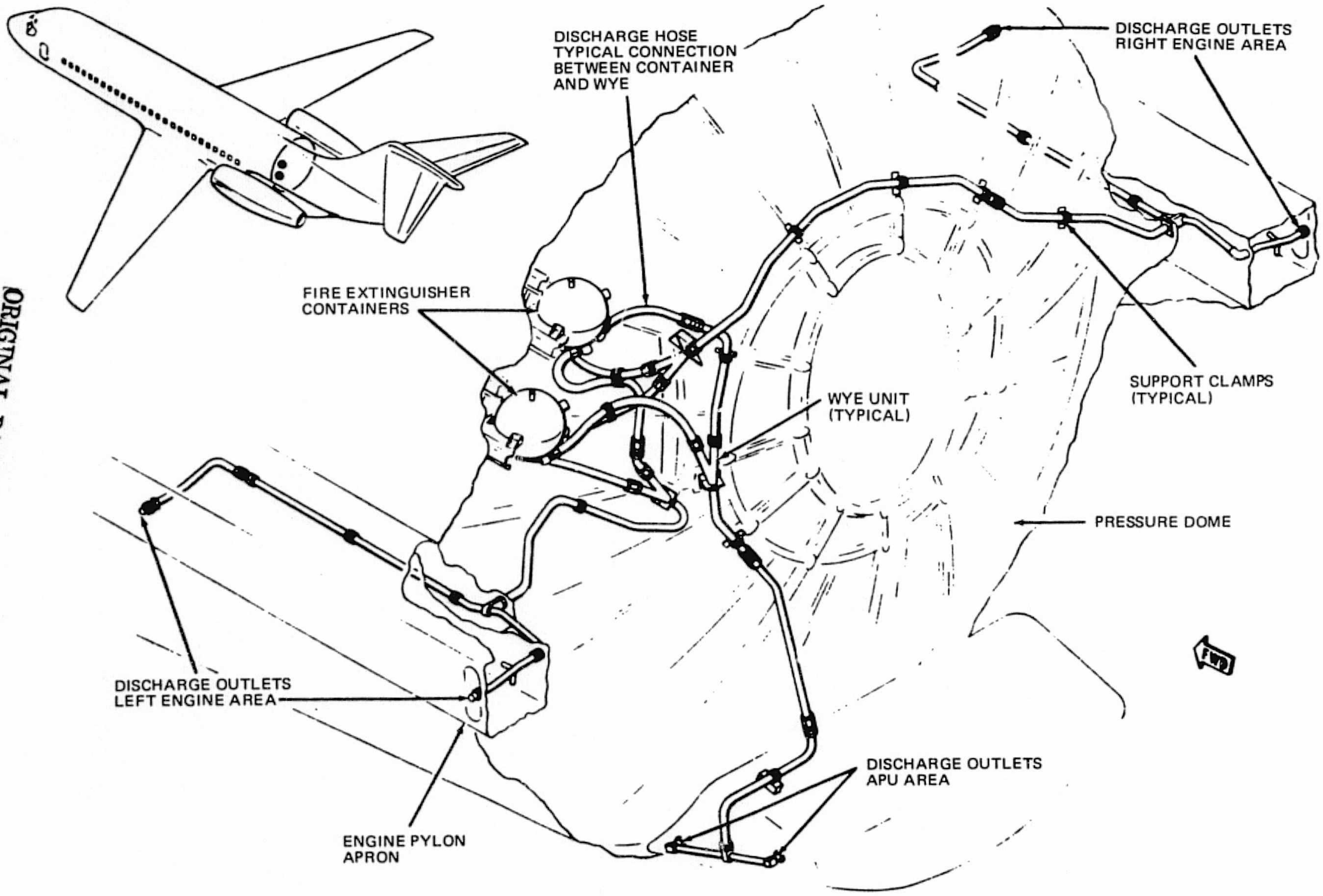

FIGURE 95. FIRE EXTINGUISHER CONTAINERS AND LINES

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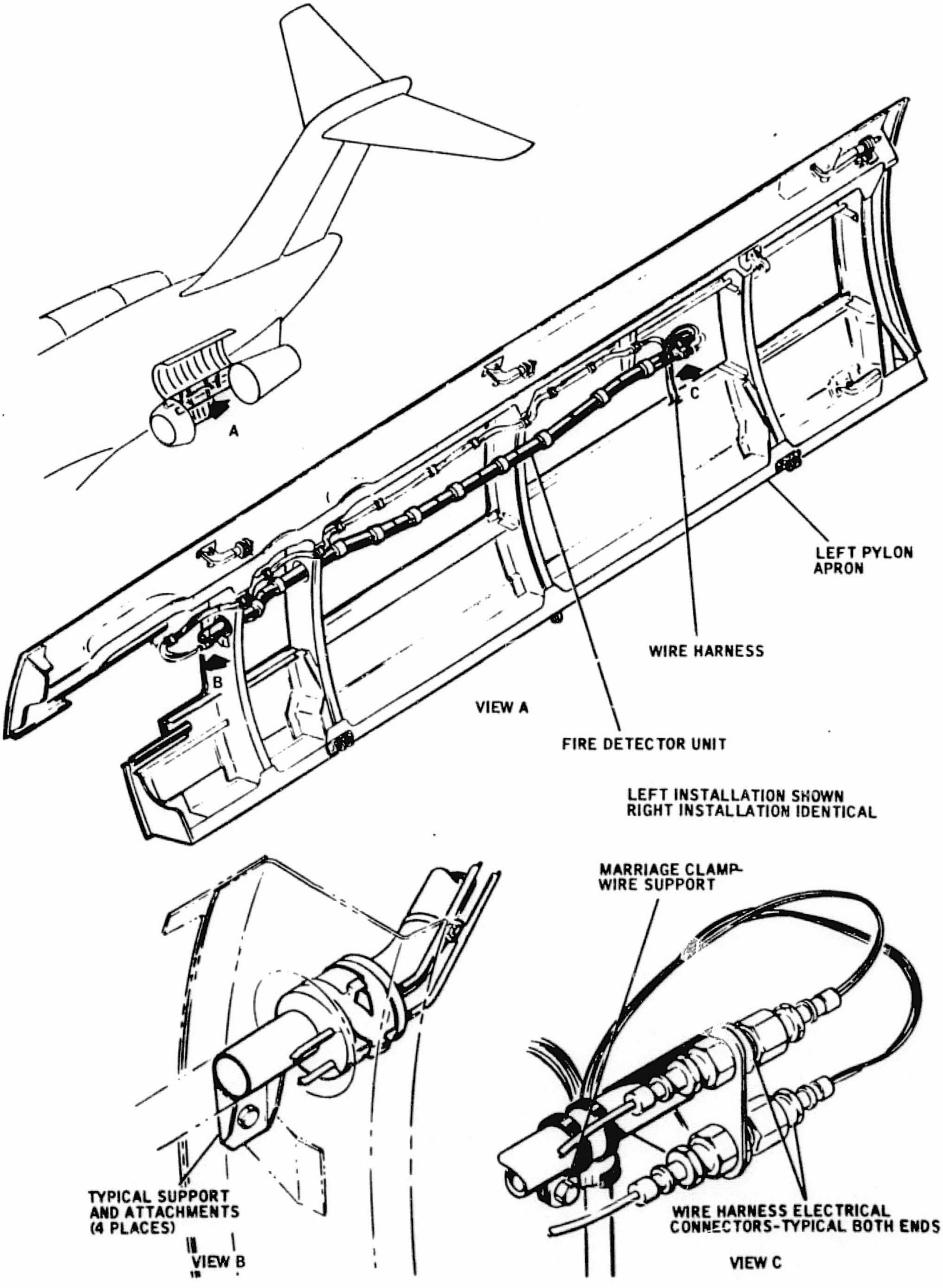

FIGURE 96. ENGINE PYLON FIRE DETECTOR LOOP

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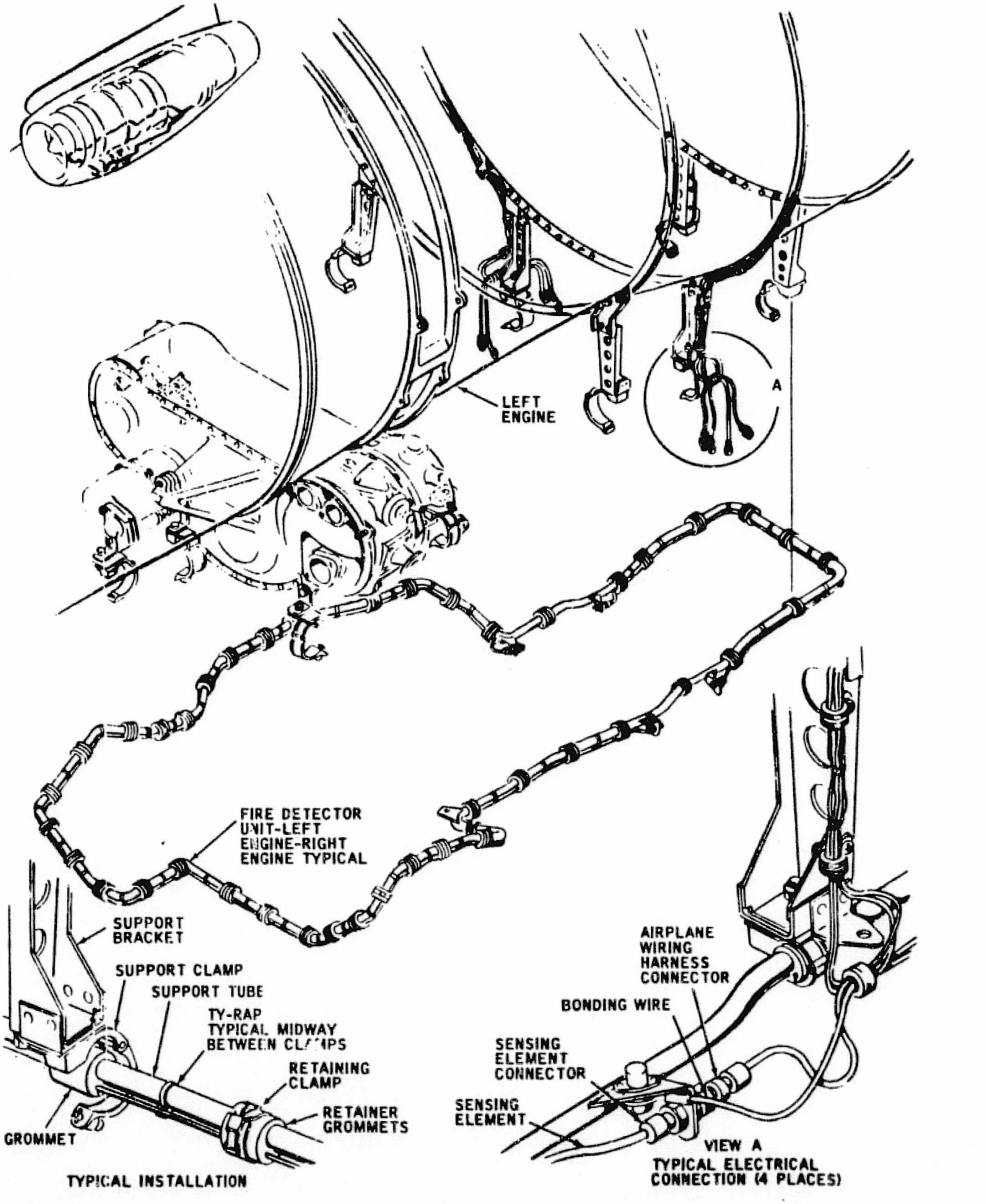

FIGURE 97. ENGINE FIRE DETECTOR LOOP

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into the mating supports to make an installation and clearance check and allow development of the engine wiring harness. See figures 75, 80, and 88. A new apron detector support tube was developed for the Refan apron and pylon using the same DC-9 detector elements. This was accomplished by utilizing pieces of the DC-9 assembly and routing the support tube as required to clear other adjacent parts. See figure 33.

APU Exhaust Outlet

The APU exhaust pipe discharges high on the right side of the fuselage and is directed to prevent impingement of hot gases on aircraft structure and the right engine upper thrust reverser. Due to the larger nacelle on the Refan DC-9 the APU exhaust outlet was reworked to add welded on turning vanes so that exhaust gases would clear the nacelle structure in the T/R door area. See figure 98.

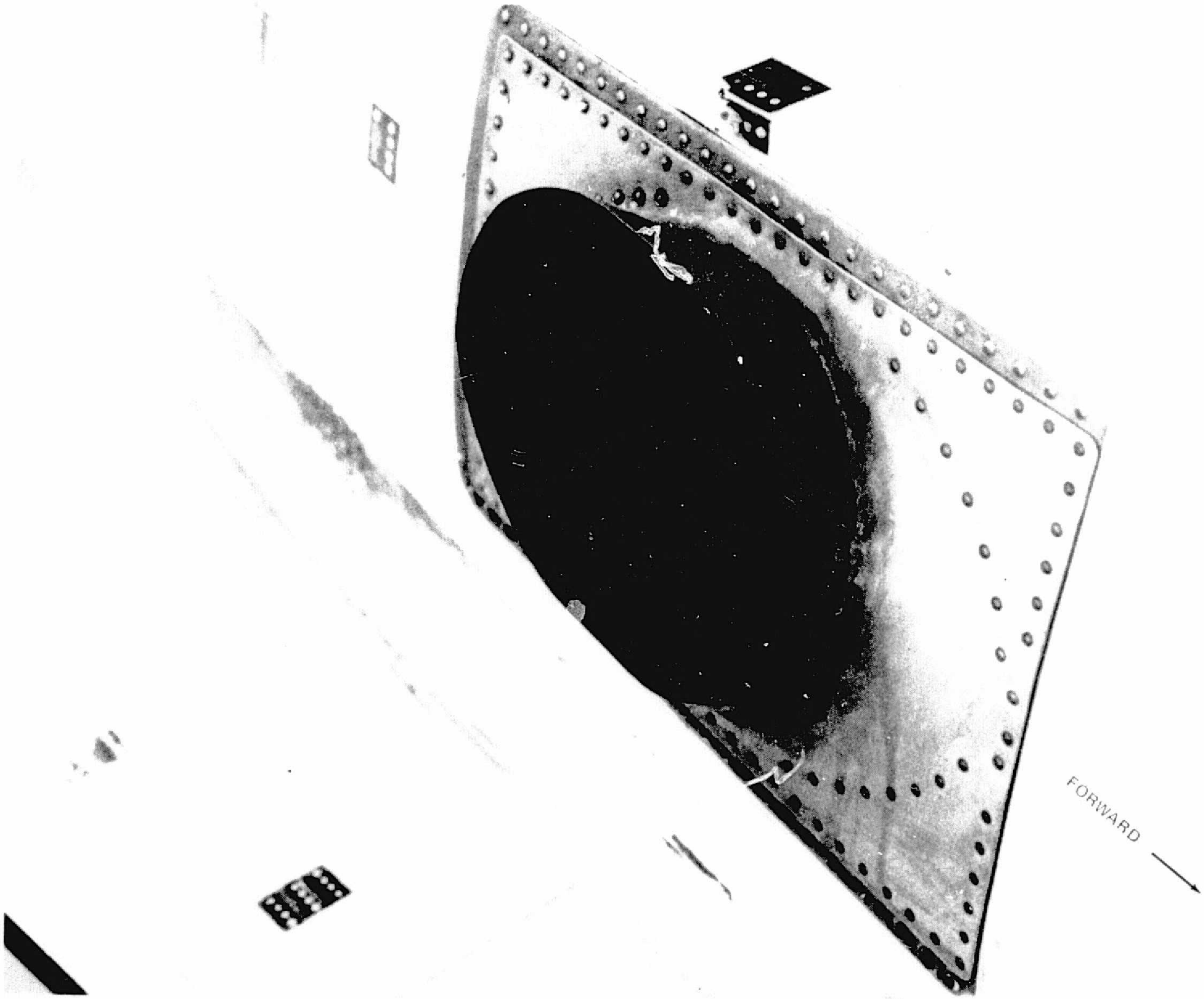

FIGURE 98. APU EXHAUST OUTLET

SUMMARY OF RESULTS AND CONCLUSIONS

The purpose of the Refan Program was to determine the technical and economic feasibility of reducing community noise of JT8D powered aircraft through modification of existing engines and nacelles. This report identifies the airplane modifications required to install the modified engines and the design and construction of the flight worthy hardware.

The JT8D-109, the Refan derivative of the basic JT8D-9 engine, was selected for installation on the DC-9-31 flight test aircraft. Since the Refan concept is to retrofit the existing fleet with quieter Refan engines, the DC-9 systems were designed for minimum change or economic impact on retrofit while achieving a desired level of performance and noise. The nacelle had a 1595.6 mm (62.82 in.) long inlet and 1816.1 mm (71.5 in.) exhaust duct. The inlet had 1234.4 mm (48.6 in.) of acoustic treatment and the tailpipe had 1305.5 mm (51.4 in.) of equivalent length acoustic treatment.

The pylon was re-designed with a width of 204.5 mm (8.05 in.). This reduced width was selected considering high speed cruise drag, low speed stall recovery and accessibility to the interface subsystems. The box structure was designed to a deflection criteria to ensure that no fatique problem would result from induced loads to the pressure bulkhead.

Fuselage frames were reinforced in the vicinity of the pylon, the titanium panels replaced in the pylon area, and the fuselage keel reinforced to account for the heavier engine and nacelle and higher thrust of the engine.

The forward engine mount was replaced with a new machined fitting to support the higher loads. The aft mount was modified by redesigning the upper attachment link.

The Refan nacelle required a new nose cowl and bullet, new lower and upper access doors, new pylon apron , a new exhaust duct and thrust reverser.

The design and construction of the nacelle hardware was similar to the production DC-9 except for the addition of extensive acoustic treatment in the inlet and exhaust duct.

Experimental type tooling and fabrication was used on all hardware. The hardware was inspected prior to and at the conclusion of each flight. No failures were reported in the Douglas hardware during the total flight program. The hardware is considered certifiable and representative of the design and hardware that would be built as retrofit kits.

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SYMBOLS

APU	auxilary power unit
CSD	constant speed drive
EPR	engine pressure ratio
IGV	inlet guide vane
L.H.	left hand
M/I	moment/inertia
N_1	low speed rotor rpm
N_2	high pressure compressor rpm
P/P	Power Plant
QEC	quick engine change
R.H.	right hand
SAM	sound absorbing material
S.I.	standard international
S/O	shut off
T/R	thrust reverser
X_N	nacelle station - positive outboard
Y_N	nacelle station - positive aft
Z_N	nacelle station - positive up